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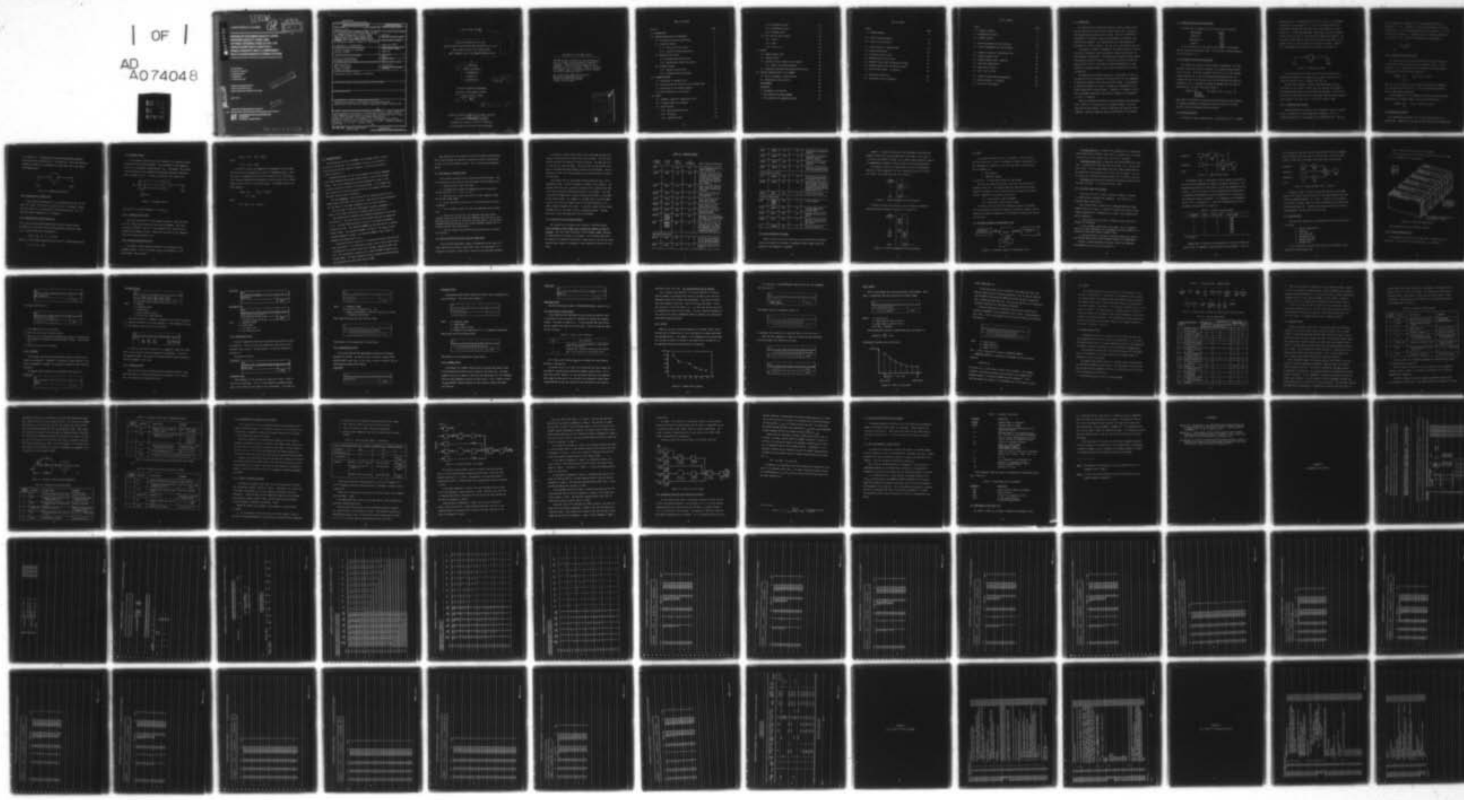

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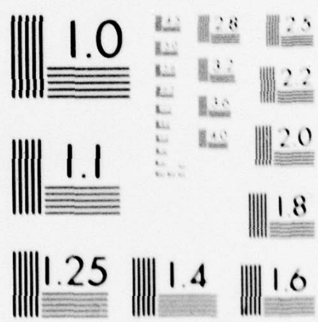

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A USER'S MANUAL FOR DMQS

DESIGN OF INCOMING QUALITY LEVEL, PROCESS QUALITY LEVEL AND OPTIMAL INTERRELATED LOT-BY-LOT SINGLE SAMPLING PLANS FOR A SINGLE-PRODUCT MULTI-COMPONENT MULTI-STAGE MANUFACTURING SYSTEM

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April 1979

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DESIGN OF INCOMING QUALITY LEVEL,

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SINGLE SAMPLING PLANS FOR A SINGLE PRODUCT

MULTI-COMPONENT MULTI-STAGE MANUFACTURING SYSTEM .

BY

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~~Illinois Institute of Technology~~

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Chicago, Illinois 60616

11 Apr 1979

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AVAILABILITY OF THE DMQS SYSTEM

The DMQS system is available to any one desiring a copy. A computer listing on paper is available at no charge. The program contains more than 2,000 statements. There is a nominal charge, to cover expenses, for a listing on tape. There is no charge if a computer tape is accompanied with the request. For further information, write:

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1.0 INTRODUCTION

The program designs manufacturing-quality control systems to minimize the expected operating cost of a single product for a user specified Average Outgoing Quality Limit, (AOQL). The costs considered are: raw materials, inspection, repair or replenishment of defectives, manufacturing and assembly. The sampling plans are single sampling by attributes on a lot-by-lot basis. The lot size is specified by the user.

The program is written in FORTRAN for the UNIVAC 1108 at the Illinois Institute of Technology and was designed for ease of modification for other computer installations. The program uses forward recursion dynamic programming to solve the problem. The decision variables include the sampling plans (n and c), the fraction defective generated by a manufacturing or assembly process, and the quality characteristics of the raw materials.

The underlying cost models assume that a large number of lots of the products are to be processed and the decision rules are independent of the actual outcome of the rules at previous stages. The generation of additional defects at a stage is assumed to be independent of the defects generated at previous stages. Inspection is assumed to be perfect, and defects generated at any previous stages are also detected if a unit is inspected.

Section 2 describes the problem, solution approach and terminology used. Section 3 is an overview of the computer program. Section 4 specifies the input format. Section 5 describes the output and interpretation. Section 6 describes possible modification of the program.

2.0 PROBLEM DESCRIPTION AND TERMINOLOGY

The model may be composed of the following types of stations:

Station Type	Symbol
Inspection	□
Manufacturing	○
Assembly	◎

In this section each of the station type's cost will be defined and the recursive relationship shown. First the basic solution approach will be discussed in 2.1.

2.1 The General Recursive Relationships

The program uses forward recursion dynamic programming. The state variable linking the successive stations is the average fraction defective in the lot. To discuss a general station, let us call the average incoming quality the p_I and the average outgoing quality AOQ. The minimum cost for all the stations up to and including the one under consideration, say n, is denoted by $f_n(AOQ)$ and depends upon the value of AOQ resulting. The basic recursive relation is

$$f_n(AOQ) = \min_{\substack{\text{decision} \\ \text{variables} \\ \text{of station } n}} \left\{ \text{stage } n \text{ cost} + f_{n-1}(\, p_I \,) \right\}$$

where AOQ is a function of p_I and the decision variable at that station. The program implementation establishes a grid of values on the state variables and any continuous decision variables.

2.2 Inspection Station

An inspection station sampling plan is specified by (n,c). A random

sampling of size n is selected from the lot (of size N). If the number of defectives in the sample is c or less, the discovered defects are repaired (or replaced with good ones) and no more inspection is done on that lot. If there are more than c defectives, the entire unsampled portion of the lot (N-n) is inspected and all defectives repaired. This is called a single sampling plan with rectification; the quality of performance will be at least as good after sampling as before. Symbolically, the inspection station may be represented as in Figure 2.1.

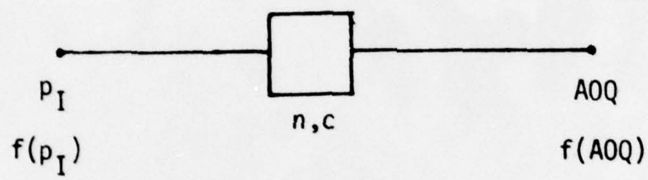

Figure 2.1 Inspection Station

For a particular value of AOQ, the utility of the inspection is considered by comparison of $f_n(AOQ)$ with $f_{n-1}(AOQ)$. Note that for an inspection station to have a feasible plan, AOQ < p_I

For the final inspection station, the average outgoing quality limit AOQL is used instead of AOQ as the state variable and $f_n(AOQL)$ is the minimum average total cost associated with the AOQL. The plan (n,c) for the final inspection station will guarantee that the average outgoing quality AOQ for any value of p_I is less than or equal to AOQL.

2.2.1 Inspection Station Costs

The expected cost of inspection at an inspection station is denoted by $k_2 \cdot$ ATI where ATI is the average total inspection: ATI = n + (N-n)(1-P_a) where P_a is the probability of accepting the lot. The cost

per unit inspected is denoted by k_2. The expected repair cost is denoted by $k_1 \cdot \text{ATI} \cdot p_I$ where p_I is the fraction defective in the lot and hence $\text{ATI} \cdot p_I$ is the expected defectives to be repaired. k_1 is the cost per unit repaired. The expected cost at an inspection station is of the form $(k_1 \cdot p_I + k_2)\text{ATI}$. The probability of acceptance is

$$\sum_{x=0}^{c} \frac{(np_I)\, e^{-np_I}}{x!}$$

2.2.2 Inspection Station Recursions

The inspection station could be associated with the inspection of raw materials or after a manufacturing or assembly station. If the inspection is of a raw material and no manufacturing has been done on the component, then the recursive relation is

$$f_1(\text{AOQ}) = \min_{p_I, n, c} \{k_4 N + (k_1 p_I + k_2)\ \text{ATI}\}$$

where k_4 is the cost/unit of the raw materials and may be a monotonically nonincreasing function of p_I. The resulting Average Outgoing Quality, AOQ, equals $p_I P_a(N-n/N)$.

If the inspection is of a component which has one or more previous manufacturing or assembly stages, the recursive relationship is

$$f_n(\text{AOQ}) = \min_{n,c} \{(k_1 p_I + k_2)\ \text{ATI} + f_{n-1}(p_I)\}$$

2.3 Manufacturing Station

At a manufacturing station, each of the N units in the lot are manufactured. Symbolically, the manufacturing station may be represented

as in Figure 2.2. The manufacturing operation generates additional defectives with a probability of p' for each unit. Thus, the resulting output has a quality of conformance no better than that of the input, and probably worse.

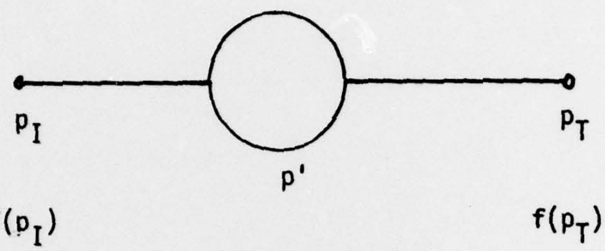

Figure 2.2 Manufacturing Station

2.3.1 Manufacturing Station Cost

If the cost/unit manufactured is k_3 the manufacturing cost for the whole lot is k_3N. The cost/unit k_3 may vary as p' is changed. Assume that the value of k_3 is monotonically non-increasing with p' (i.e. k_3 stays the same or decreases as p' increases).

2.3.2 Manufacturing Station Recursions

Let $f_{n-1}(p_I)$ be the minimum expected cost for the station previous to stage n as a function of the fraction defective incoming to stage n, p_I. Then the recursive relationship is

$$f_n(p_T) = \min_{p'} \{N \cdot k_3 + f_{n-1}(p_I)\}$$

where p_T is the average outgoing quality level for a manufacturing stage

$$p_T = p' + p_I - p'p_I.$$

2.4 Assembly Station

At an assembly station two or more components are assembled (and/or processed) into a single component. The aggregation of the components results in an Aggregate Incoming Quality, p_{AI}. Furthermore, the assembly and/or processing of the components may generate additional defectives with a probability of p'. Figure 2.3 represents this symbolically.

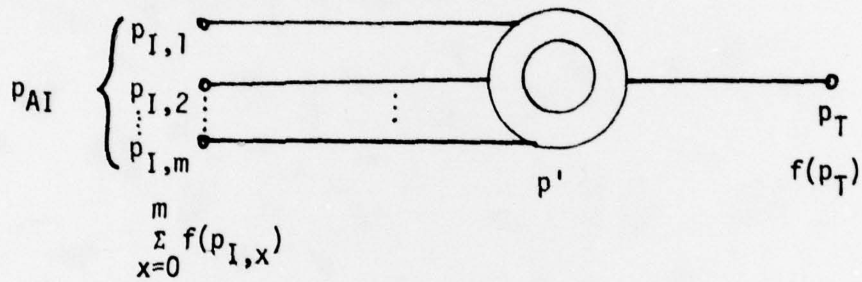

Figure 2.3 Assembly Station

The quality of incoming component x is called $p_{I,x}$.

2.4.1 Assembly Station Costs

Let k_5 by the cost/unit of the assembly operation. Then the assembly cost is Nk_5 because the entire lot must be assembled. This cost/unit may be allowed to vary as p' (the probability of a defective generated by the assembly) varies. Assume that the value of k_5 is monotonically non-increasing function of p'.

2.4.2 Assembly Station Recursions

The assembly station recursion consists of two phases for each assembly station. In the first phase, $f(p_{AI})$ is determined. In the second phase, the recursion is

$$f_n(p_T) = \min \quad \{Nk_5 + f(p_{AI})\}$$

where

$$p_T = p' + p_{AI} - p'p_{AI}.$$

In the first phase, the components are aggregated first by aggregating the first two components to obtain an aggregated $\hat{f}(p_{AI})$. Then the result is aggregated with the third component to get a new $\hat{f}(p_{AI})$. This continues aggregating one additional each time until all are aggregated, and the result is then called $f(p_{AI})$. The general step in this phase would be

$$\hat{f}(\hat{p}_{AI}) = \min_{p_{I,x}\,,\, p_{AI}} \quad \{f(p_{I,x}) + f(p_{AI})\}$$

where

$$\hat{p}_{AI} = p_{AI} + p_{I,x} - p_{AI}p_{I,x}.$$

3.0 PROGRAM OVERVIEW

The program was written in FORTRAN V on the UNIVAC 1108 at Illinois Institute of Technology. It was designed for ease of use at other installations and on other types of computers. The files used are described in Section 4.1.

The manual describes the use of the program for the multi-component, multi-stage manufacturing system in which there is one or more assembly stages. The single-component multi-stage manufacturing system is thus a special case and is treated in the obvious manner. It is assumed that each station has at most one successor and only an assembly station may have more than one direct predecessor.

The term <u>component</u> is used to describe the (perhaps) partially completed product resulting from any station. Note that the output (component) for one station is the input (component) for its direct successor.

The term stage is from the terminology of dynamic programming. It refers to the column location on an assembly chart (Section 4.2).

The program has an elaborate input checking system which is described in Section 4.0. The basic rules for the problem structure are summarized in 3.1. The algorithms described in Section 2 use dynamic programming forward recursions. The subroutine PRØDN uses the algorithm for a manufacturing station. The subroutine ASSMBY is called to find $f(p_{AI})$ as each assembly component is added. The subroutine PRØDN is then called to determine the minimum cost for p_T.

Since the ATI term is used for all inspection stations except for the final inspection, it is convenient to create a set of tables which results in minimum ATI for various values of p_I and AOQ. Subroutine INSP1 does this. The calculations varying p_I for a specified AOQ are done by subroutine INSP2. The final inspection station, subroutine INSFIN performs the optimization to obtain the specified AOQL.

Upon processing of the station for the final product, backtracking must be done through the sequentially generated station solution table in order to find the optimal solution. This is done by the subroutine BAKTRK.

3.1 Consistency of Assembly Chart

The following conditions must be met when using the program. They are referred to as the rules for the consistency of the assembly chart.

1. There must be at least two stages.

2. The numbering of stages and components must be consecutive starting from one, i.e. 1, 2, 3,..., etc.

3. There must be at least one station for each component number and for each stage number.

4. *No two inspection stations can be placed consecutively along* a component.

5. For an assembly station at least two components must be assembled.

6. There can be one and only one component resulting from an assembly station and for the resulting component there must be at least one station (of any type) in one of the following stages. The resulting component number must be one of the incoming component numbers for the assembly station under consideration.

7. The last stage of the manufacturing system must be an inspection station.

3.2 State and Decision Variable Grids and FMAX Value

Since the algorithm employs dynamic programming and the state variables and decision variables (other than n and c) are continuous, it is necessary to provide a finite grid of values for the continuous variable.

In practice it makes little sense to use a grid smaller than 0.5% because of the accuracy of controls and cost estimates. The user must provide the grid size desired for these variables. The same grid size is used for all state variables. The grid sizes for the decision variable for manufacturing and assembly stations may be different. The program uses 0.5% for the finest possible grid size and rounds all values on that basis.

The maximum limit on the average fraction defective from a lot is conceptually 100%. Usually the range of interest is much smaller. The program allows the user to specify a maximum which is smaller than 100%. This allows a possible suboptimal solution to be obtained. The limit is specified by employing a constant multiplicative factor, called FMAX on the value of AOQL. For example, if the AOQL value is 0.05 and FMAX value is 2.0, then, the maximum value of the state variable is 0.10 (FMAX * AOQL) throughout the system. It should be noted that the larger the FMAX value is, the more unlikely a suboptimum becomes. However the price is that the computation time is prolonged.

3.3 Explanation of the Program Elements

The program has 23 elements, one of which is the MAIN program. Every statement in each element has a sequence of numbers for ease of ordering. The first three characters of the statement number represent an abbreviation of the name of the element. The following table gives the names of the elements (subroutines), where they are called from, their abbreviations, number of statements in each element and their basic functions.

Table 3.1 Program Elements

Program Element	Called From	Abbre-viation	# of Statements	Basic Function Performed
MAIN	-	MIN	107	Sets parameters and calls other subroutines.
CØNTRL	MAIN	CTL	398	Controls calling of sub-routines according to the structure of a problem. It also defines the Random Access File and controls output.
INPUT	MAIN	IPT	369	Reads input and controls other input reading sub-routines.
RAWMAT	INPUT	RAW	87	Reads inputs costs for raw materials.
INSPEC	INPUT	ISP	42	Reads input costs for inspection station.
PRØCES	INPUT	PCS	77	Reads input cost for manufacturing station.
ASSEMB	INPUT	ASM	80	Reads input costs for assembly station.
CØSTFN	PRØCES ASSEMB RAWMAT	CFN	84	Generates cost coordinates according to the specified cost functions 1,2,...,9.
RANK	PRØCES RAWMAT ASSEMB	RNK	72	Ranks the set of cost co-ordinate pairs to determine whether or not they are monotonically non-increasing function of p.
Algorithm Subroutines				
PØISSN	INSP1	PSN	17	Calculates the probability of acceptance based on Poisson Distribution.
INSP1	ATINC	IP1	73	Generates tables of ATI, n and c.

INSP2	CØNTRL	IP2	125	Algorithm for inspection station.
INSFIN	CØNTRL	IFN	71	Algorithm for Final Inspection Station.
ASSMBY	CØNTRL	ABY	68	Algorithm for assembly station.
PRØDN	CØNTRL	PDN	87	Algorithm for manufacturing and assembly station.
Subroutines for Output				
DISK	CØNTRL	DSK	39	Writes station outputs to the Random Access File.
BAKTRK	CØNTRL	BTK	93	Backtracking according to the structure of the problem obtains and reports optimal solution from the Random Access File.
DATOUT	MAIN	DAT	75	Prints some outputs.
Auxiliary Subroutines				
HEAD	CØNTRL DATØUT INPUT	HED	10	Prints heading.
SETMX	CØNTRL	SMX	19	Arranges data before calling INSP2.
ATINC	MAIN	ANC	82	Arranges data and calls INSP1.
ZERØIN	INSP1	ZEN	52	Searches for value of n for each values of AIQ, AOQ, and c.
FCT	ZERØIN	FCT	72	Function subroutine.

3.4 Size Limitations of Program

There is really no limit to the size of the problem that the program can solve in terms of the number of components and/or stages unless the capacity of the computer is exceeded.

However, it should be pointed out that a maximum of only 999 components of each type can be accommodated in any stage. Since there is no limit on the number of stages, we can always create additional stage(s) to accommodate any number of excess stations of one type beyond 999.

For example, if we have a problem which requires 1500 components and each of these components has to be inspected as soon as it enters our system. The problem may look like Figure 3.1.

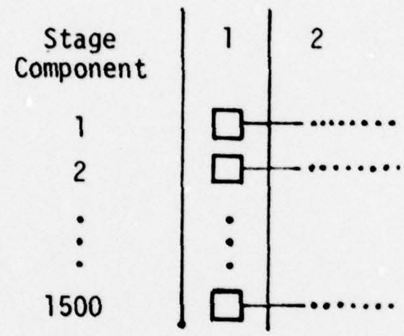

Figure 3.1 Wrong Arrangement for Size Violation

In order to satisfy the constraint, we can create an additional stage and perhaps arrange the stations as in Figure 3.2.

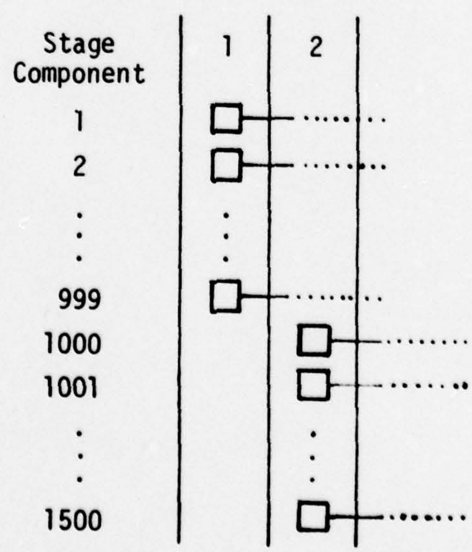

Figure 3.2 Correct Arrangement for Size Violation

4.0 INPUT

This program package consists of 23 elements, 2 of which can be modified by the user in order to accomodate a bigger size problem (e.g. more components or stages) or to fit their own type of cost function. The two elements are

1. MAIN Program
2. SUBROUTINE CØSTFN.

See Section 6: Possible Modifications of the Problem.

The users are required to prepare input data and place them on a sequential data file. The program reads the input data and provides diagnostic messages (if any) so that the user can correct their input easily. Diagnostics are usually the result of

(i) miss-typing of input statements.

(ii) dimensions of some arrays exceeded.

If there is any error that the program can detect, the program will not proceed to calculate the optimal solution but instead a partial output with diagnostic messages will be provided to identify the sources of the errors.

4.1 Schematic Diagram of Input/Output Files

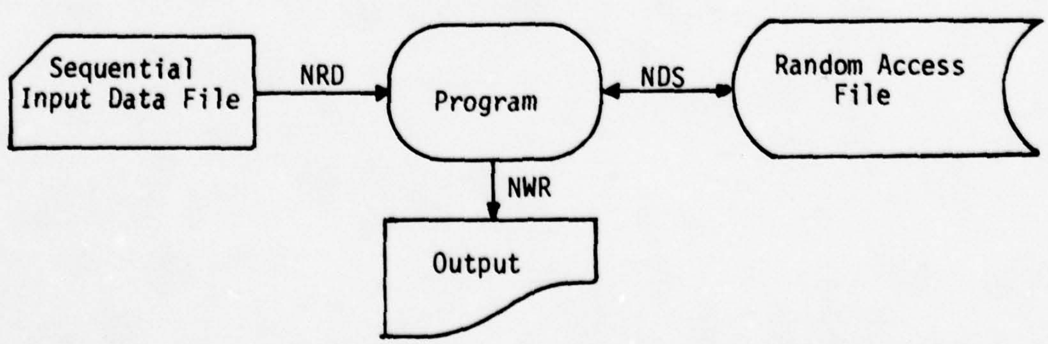

Figure 4.1 Schematic Diagram of Input/Output Files

The Input Data File is assumed to be sequential and is read by the I/Ø-variable-name called NRD. Each record is assumed to be of 80 bytes long (similar to an 80 column card). The file is formatted.

The Random Access File is created by the Fortran DEFINE FILE statement. The program will determine the size of this file. Its I/Ø variable is NDS. If the program detects any error (hence computation will be terminated by the program) this file will not be created. It is to be created as an unformatted 48-byte record file, if there is no error.

The Output File assumes the standard 133 character record file for the paper printouts. Its I/Ø variable name is NWR.

4.2 To Create Input for a Problem

Since there are only 3 types of stations allowed in a problem i.e. Manufacturing, Assembly and Inspection. The letters M, A, I, represent them, respectively.

Every station must be identified by component-number and stage-number as well as its type. In addition a station may or may not have a name associated with it depending on its type. The following rules must be adhered to:

1. Each station in the system is allowed to have a name with a maximum of 4 characters.

2. Every assembly station must have a name. This is necessary since two or more components will be assembled into one and hence it is necessary to know which station assembles them.

3. Naming for M and I stations is optional because such stations are uniquely identified by their component-numbers and stage-numbers.

Consider a simple manufacutring system in which two components are assembled into one unit as in Figure 4.2.

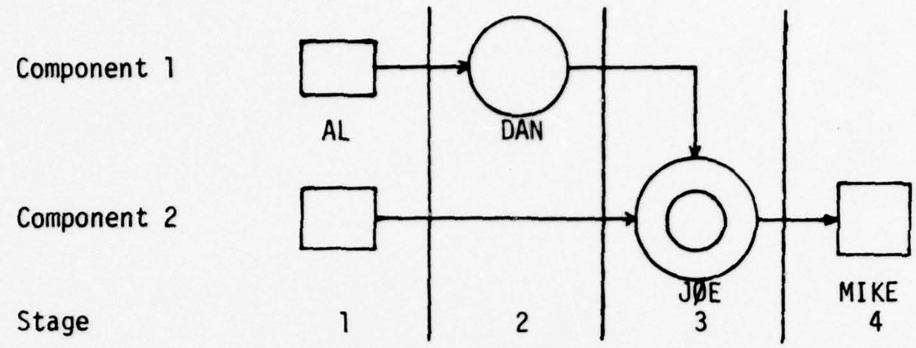

Figure 4.2 Example Assembly Chart

The assembly chart is constrained to be as compact as possible to the left and the components and stages are numbered accordingly. This manufacturing system can be described as having two components and four stages. In the third stage, the first component after manufacturing is assembled with component 2, and the assembled unit is inspected at the inspection station called MIKE. This component could be numbered either 1 or 2 - See Section 3.1. (See also STRUCTURE Section 4.3.2.) We identify the problem as in Table 4.1.

Table 4.1 Example Structure Naming

Component	Stage	Station Type	Station Name
1	1	I	ALƀƀ*
1	2	M	DANƀ
1	3	A	JØEƀ
2	1	I	ƀƀƀƀ
2	3	A	JØEƀ
2	4	I	MIKE

* ƀ = blank

Suppose that, in reality, we are producting a lot size of 1000 units and two units of component #1 are required for each assembly. Since all

lot sizes must be the same, then we create another ficticious component called #3 which is the same item as #1, each with a lot size of 1000. Figure 4.3 shows how the assembly chart would have to be modified.

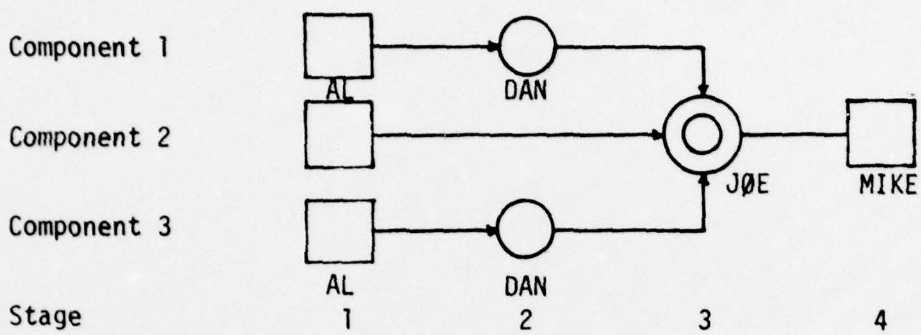

Figure 4.3 Example Assembly Chart - Modified

Although in Stage 1, we have 2 inspection stations called "ALbb" they are not taken as the same station by the program because they have different component-numbers, i.e. 1 and 3. Similarly for the processing stations in stage 2, they are treated independently even though they have the same name, DAN. Therefore cost data must be given for each of them seperately, but the data will be the same.

4.3 Input Sections

The input data required by the program may be divided into sections as follows:

1. QUALITY CHARACTERISTICS
2. STRUCTURE
3. INSPECTIØN CØST
4. RAW MATERIAL CØST
5. MANUFACTURING CØST
6. ASSEMBLY CØST

It is instructive to consider each record in the sequential input data file as an 80-column card.

Note: Columns 61-80 are reserved for comments.

Each input section has a title card and the last card in the data file is the ENDATA card as shown below.

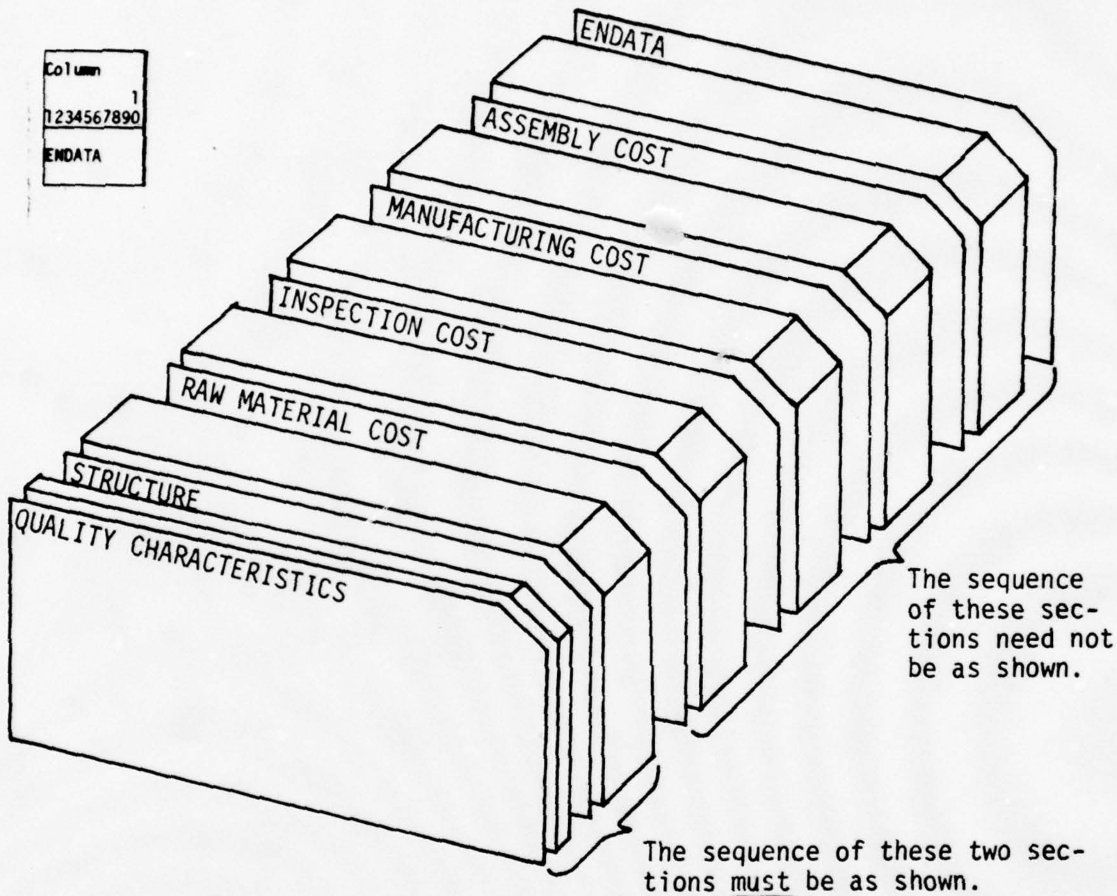

Figure 4.4 Input Data Organization

Each section will now be discussed in detail.

4.3.1 Quality Characteristics

This section must be first in the data file. It consists of two cards only. The first card is the title card. Its content is:

Column 1234567890123456789012345678901234567890123456789012345678901234567890123456789O	
QUALITY CHARACTERISTICS	
	Comments

The second card format is:

Column 12345678901234567890123456789012345678901234567890123456789012345678901234567890									
5X	F5.3	5X	F5.3	5X	F5.3	2X	I8		
	a		b		c		d		Comments

a = Final AØQL desired for the problem

b = Grid size to be used for state variable

c = FMAX, this is a factor which establishes the range of p values which the program will examine to find the optimal solution. (See Section 3.2)

d = The lot size of the final product

4.3.2 Structure

This section describes the manufacturing stations involved in the system to the computer. Although it is natural to input stations in the order of components or stages, the program can handle any order the user may desire.

The general input format for the STRUCTURE input section is:

Title card

Column 12345678901234567890123456789012345678901234567890123456789012345678901234567890	
STRUCTURE	
	Comments

Subsequent Cards

```
Column
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

5X	I5	I5	A1	A4	I5	A1	A4	I5	A1	A4	I5	A1	A4	I5	A1	A4	
a	b	c	d	e	c	d	e	c	d	e	c	d	e	c	d	e	Comments

where a = blanks

b = component number

c = stage number

d = type of station (M,A,I)

e = station name (Alpha Numeric)

Each card specifies a component, therefore it can contain a maximum of 5 stations belonging to the same component. For the example of section 4.2, the complete input data is as shown below:

```
Column
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
STRUCTURE
         1    1IALƀƀ    2MDANƀ    3AJOEƀ                    FIRST COMPONENT STNS
         2    1Iƀƀƀƀ    3AJOEƀ    4IMIKE                    SECOND COMP STATIONS
```

If there are more than 5 stations for a component, repeat the format until all the stations along the component are completed. If you omit the component number, the program will assume that the station belongs to the last component it has read.

4.3.3 Inspection Costs

These are units costs associated with an inspection station. Costs associated with all inspection stations must be grouped in this section. Each card represents an inspection station.

Title Card

Column 1234567890123456789012345678901234567890123456789012345678901234567890123456789 0	
INSPECTION COSTS	
	Comments

Subsequent Card

5X	I5	I5	5X	F10.2	F10.2		
	a	b		c	d		Comments

where a = component number

b = stage number

c = unit repair cost

d = unit inspection cost

4.3.4 Raw Material Costs

The basic components entering the manufacturing system are called raw materials. Their unit costs corresponding to qualities (p) are entered in this section. See descriptions of the cost functions in Section 4.4.

The general format is

Title Card

Column 1234567890123456789012345678901234567890123456789012345678901234567890123456789 0	
RAW MATERIAL COSTS	
	Comments

Subsequent Cards

Each component of the raw materials requires at least 2 cards to specify its coordinates. The first card identifies component number, types of cost functions and number of cost coordinates. Its format is:

Column
1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

5X	I5	I5	I5		
	a	b	c		Comments

where a = component number

b = type of cost function (0,1,...,9)

c = number of coordinates if the cost function is of type 0; otherwise leave blank.

Other cards following this card have the format:

Column
1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

10X	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	
	*	*	*	*	*	*	*	*	*	*	Comments

*See Section 4.4 for explanation of these fields.

4.3.5 Manufacturing Costs

Cost associated with the manufacturing stations are inputted through this section. The form of input is similar to that of RAW MATERIAL CØSTS except that, in this case, we have to identify the component and the stage of the station.

Title Card

Column
1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

MANUFACTURING COSTS	
	Comments

Subsequent Cards

Each manufacturing station requires at least 2 cards to describe its cost coordinates. The first card's format is:

Column

5X	I5	I5	I5	I5		
	a	b	c	d		Comments

where a = component number

b = stage number

c = type of cost function

d = number of cost coordinates if c = 0; otherwise leave blank

Other cards have the following format:

Column

10X	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	
	*	*	*	*	*	*	*	*	*	*	Comments

*See Section 4.4 for explanation of these fields.

4.3.6 Assembly Costs

The formats for assembly station costs are exactly the same as those of the manufacturing station costs, except for the title card. For each assembly station, one needs to input the cost coordinates only once although there are many components running into the station. This is done by selecting <u>any</u> component number belonging to that station as having the proper cost function.

Title Card

Column 1234567890123456789012345678901234567890123456789012345678901234567890123456789	
ASSEMBLY COSTS	
	Comments

Subsequent Cards

See the corresponding format of MANUFACTURING CØSTS, Section 4.3.5.

4.4 Cost Function Input Formats

A cost function which describes the cost versus the quality level is required for every raw material, manufacturing station and assembly station. Ten types of codes (0,1,...,9) are provided (See also Section 6.2) to identify the types of cost functions. Table 4.2 shows the types of cost functions.

Table 4.2 Types of Cost Functions

Type	Cost Function
0	Every pair of cost coordinates is individually given to the program.
1	Standard cost function supplied by the program.
2,...,9	User's cost functions in functional form.

All of these cost functions must be a monotonically nonincreasing function of the quality.

In Sections 4.3.4, 4.3.5 and 4.3.6 we describe the input formats for raw material, manufacturing station and assembly station costs. All of these have similar formats i.e., one card which identifies the component (and stage) and the type of cost function; and subsequent card(s) where interpretations of data are conditional upon the type of cost function

specified in the first card. The interpretations are as follows:

For a station or raw material, if the cost function is of type 0, then the number of coordinate pairs must be inputted in the first card. Subsequent card(s) will contain the coordinates. Five pairs of coordinates are allowed on each card. (See Section 4.4.1 for more.) If the cost function is one of the types 1,2,...,9, then only the next card will be considered as related to the station. The cost function parameters on this card will be used by SUBROUTINE CØSTFN to generate cost coordinates. (See Section 4.4.2 and 4.4.3.)

4.4.1 Type 0

When the cost data cannot be expressed in functional form or only a discrete set of alternatives are to be considered, the known coordinates are inputted directly. For example, if for Component #3 of the raw materials, we have a choice of 6 brands of the same kind of raw material, we can represent them by the cost function of Figure 4.5.

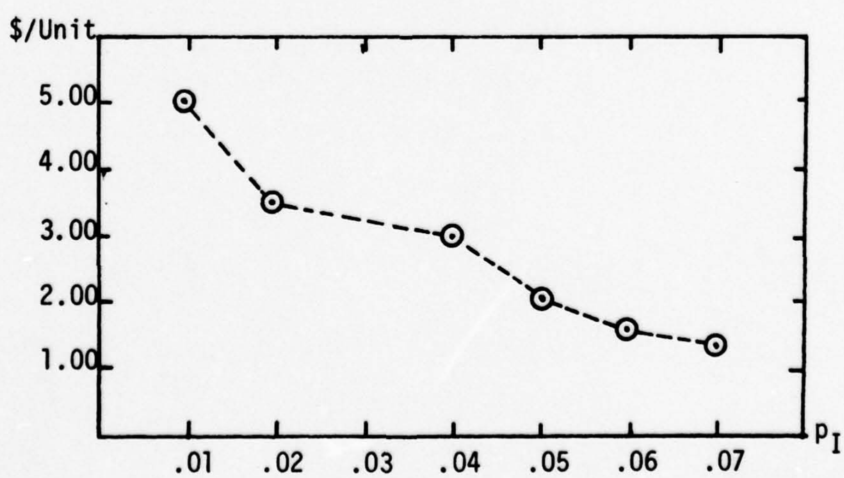

Figure 4.5 Sample Cost of Type 0

To input data in the RAW MATERIAL CØSTS section for this component, the first card is:

Column 1234567890	1234567890	1234567890	1234567890	2345678901234567890123456789012345678901234567890	1234567890123456789012345678901234567890
5X	3	0	6		
	compo-nent	type	# of coordinates		Comments

The general format for subsequent card(s) is:

Column 1234567890											
10X	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	
	p	$	p	$	p	$	p	$	p	$	Comments

$ represents the cost/unit at a specified value of quality level, p.

Hence for this component, 2 cards are required and the coordinate pairs are packed left justified as follows:

Column 1234567890											
	.01	5.0	.02	3.50	.04	3.00	.05	1.50	.06	1.50	FIRST 5 PAIRS
pair #	1	1	2	2	3	3	4	4	5	5	Comments

Column 1234567890											
	.07	1.20									LAST PAIR
pair #	6	6									Comments

4.4.2 Type 1

This is the standard cost function supplied by the program. Once type 1 is specified, the next card has the following format:

Column
1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

10X	F5.3	F5.3	F5.3	F5.3	F5.3		
	a	b	c	A(1)	A(2)		Comments

where: a = grid size of p

b = lower bound on value of p (b>0)

c = upper bound on value of p (c>b)

A(1), A(2) = constants

The corresponding equation to generate the cost coordinates is:

$$[\$/\text{units}] = \frac{A(1)}{p} + A(2)$$

Figure 4.6 illustrates the cost function.

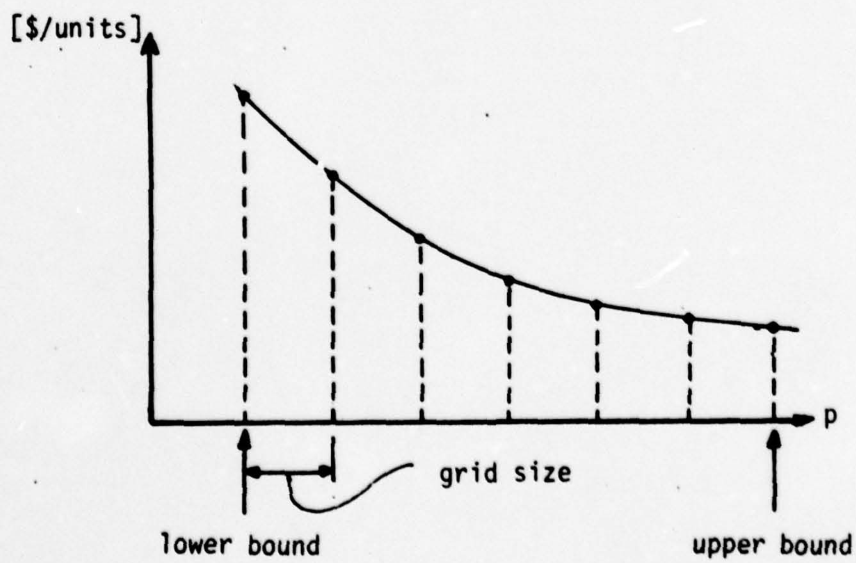

Figure 4.6 Type 1 Cost Function

4.4.3 Type 2,3,...9

If the user wishes to use a functional form other than Type 1 and does not want to put all the cost coordinates in as for type 0, then the user may modify the subroutine CØSTFN to specify the user's functional form. Section 6.2 describes this. The user may specify up to 8 additional functional forms and call them Types 2 through 9.

If one of these types is specified, only one card containing the values of parameters for that functional form is input. Seven parameters, A(1), A(2),...,A(7), are allowed to be used in any of these cost functions. The format is:

Column

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

10X	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	F5.3	
	a	b	c	A(1)	A(2)	A(3)	A(4)	A(5)	A(6)	A(7)	Comments

where a = grid size of p
b = lower bound of p
c = upper bound of p

A(1),...,A(7) = constants to be used in SUBROUTINE CØSTFN.

SUBROUTINE CØSTFN, as supplied by the package, has the functional equation:

$$[\$/\text{unit}] = \frac{1}{p}$$

for types 2,3,...,9 but these are given only as examples. For example, to specify a different functional form for Type 2, the statement with statement number 2 in Subroutine CØSTFN would be changed to: 2 FN = "your functional form using up to 7 parameters and X is the quality level".

5.0 OUTPUT

This chapter provides the characteristics of the outputs as well as their interpretations. Two options of the outputs are given: namely, the complete output (intermediate output and summary output), and only the summary report table. Both are obtained through the variable NPRT in the main program. NPRT equals 1 if the former is desired, zero if the latter is desired. The default option is complete output. Section 5.1 gives the contents of the summary report table and Section 5.2 gives the contents of the complete output. The interpretation of the complete output and the diagram of the optimal solutions to an example problem are discussed in Sections 5.3 and 5.4.

5.1 Summary Report Table

As mentioned, when the user requests only the final solution, the main program must be modified to make the variable NPRT = 0. In effect, the summary report table is printed immediately after all input images and the program limitation indicators which are explained in Section 6.1.2.

The following discussion will illustrate the output for the example given in the Appendix. The input stream and the complete output are presented as an aid to the user.

The summary report table consists of sixteen columns, which provide the information needed for each station. The information is printed station by station first component to the last, starting with the last stage first and proceeding to the first.

The following gives the list of column headings.

Table 5.1 Column Headings - Summary Report

1	2	3	4	5	6	7	8	9
STATION NAME	STAGE	COMPO-NENT	TYPE OF STN	SAMPLING PLAN		PROCESS FRAC. DEFECT	*STATE VARIABLE	
				N	C		AØQ	AØQL

10	11	12	13	14	15	16
*STATE VARIABLE		STAGE COST	MINIMUM EXPECTED COST F*	SUB ØPT IND	ALT SOLN IND	REMARKS
P_I	P_T					

Table 5.2 indicates which columns are used for each type of station.

Table 5.2 Output Column Usage

COLUMN NUMBER	DESCRIPTION	Station type (x - required) ASSEMBLY** First line (PRØD subr.)	ASSEMBLY** the following lines (ASSMBY subr.)	INSPEC-TION	MANUFAC-TURING
1	Station name	X		X	X
2	Stage number	X	X	X	X
3	Component number	X	X	X	X
4	Type of station	A	A	I	P
5	Sample size			X	
6	Acceptance number			X	
7	Process fraction defective	X			X
8	Average outgoing quality			X	
9	Average outgoing quality level			X	
10	Incoming quality	X	X	X	X
11	Process outgoing quality	X			X
12	Stage cost	X#		X#	X#
13	Minimum expected Cost (F*)	X		X	X
14	Suboptimal indicator	X	X	X	X
15	Alternative solu-tion indicator	X	X		
16	Remarks	*	*		

** There are two types of information for each assembly station; because for every "m-component" assembly station, subroutine ASSMBY, (see Chapter 3, package overview and Appendix 1) is called (m-1) times in order to determine aggregate qualities then subroutine PRØD is finally called. Therefore, in total, m lines of information are recorded for each assembly station.

In the first stage and for any type of station, stage cost shown excludes the raw material costs. In other words, the raw material costs can be determined by subtracting stage cost from minimum expected cost (F*). The first stage of a component need not be an inspection station.

5.2 Complete Output

Besides the summary report table, the user may need the intermediate outputs of all state variable values, station by station, for all stages as well as three tables derived from the INSP1 subroutine, namely the average total inspection table, sample size table, and acceptance number table. The average total inspection table, the sample size and acceptance number tables are entered by the incoming quality and the average outgoing quality level values. The information will serve the user as a source for the conventional DP iterative solution trace back. This, in turn, enables the user to obtain the solutions manually for sensitivity analysis.

After the INSP1 output, the solution table of each station is printed, station by station, component by component, stage by stage, all starting from the first to the last. This will be followed by the summary output as described in Section 5.1. An inspection station or manufacturing station requires one table. In an "m-component" assembly type station, two types of tables are printed out. The first ones are called "aggregate incoming quality" tables and (m-1) tables of this kind are printed. The last table contains the same kind of information as a manufacturing station table and refers to

the additional defectives generated by the assembly. Therefore, for each assembly station, m tables are printed. All stations are identified by component number, stage number, station type and station name, (if any) in headings. Table 5.3 gives the information for an Inspection station, as conceptualized in Figure 2.1.

Table 5.3 Inspection Station Output

COLUMN NUMBER	VARIABLE	DESCRIPTION	REMARKS
1	AOQ	Average Outgoing Quality	AOQ $\leq$ AOQL State variable
2	AOQL	Average Outgoing Quality Limit	
3	N	Sample size "n"	Decision variable
4	C	Acceptance number "c"	Decision variable
5	PIY	Incoming Quality Level "p_I" (Optimum for AOQ)	State variable from previous stage
6	STAGE COST	Inspection and Repair Costs	Does not include raw material cost
7	FØ	Minimum Average Cost Thus Far (f_n)	$f_n = f_{n-1}$ + STAGE COST
8	KSUB	Suboptimal Indicator	(see Section 5.4)

Table 5.4 gives the information generated for a Manufacturing station as conceptualized in Figure 2.2.

Table 5.5 shows the output for the (m-1) tables for an m-component assembly station. Figure 5.1 illustrates the notion of this recursive aggregation of components.

In effect, Figure 5.1 shows the computer programming aspect which was discussed in Section 2.4. The ASSMBY subroutine is called (m-1) times,

according to Figure 2.3, to determine recursively the minimum cost aggregate incoming quality for that assembly station. The first call on ASSMBY would treat $p_{I,1}$ as PI1 and $p_{I,2}$ as PI2, this results the values of PAI with the values of optimum PI1, PIA1 and optimum PI2, PIA2. These values are stored and printed in the first table (if complete output is desired). The second call on ASSMBY would treat PAI from the first table as PI1 and $p_{I,3}$ as PI2, the new values of PAI with the values of optimum of previous PAI, PIA1 and optimum $p_{I,3}$, PIA2. The calls continue in this manner (m-1) times where the PAI from the (m-1) st call represents the aggregate incoming quality for that assembly station.

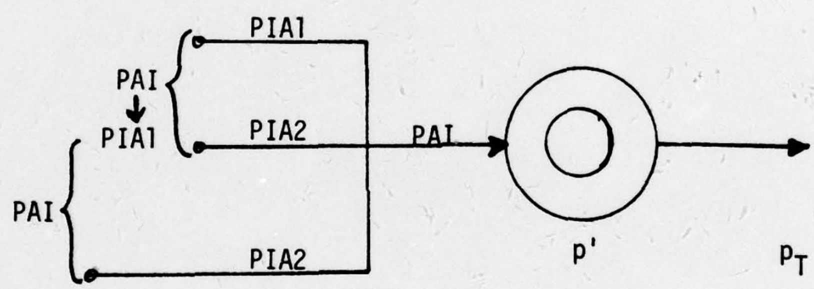

Figure 5.1 Assembly Station Quality Aggregation

Table 5.4 Manufacturing Station Output

COLUMN NUMBER	VARIABLE	DESCRIPTION	REMARKS
1	PT	Average Outgoing Quality (p_T)	State variable
2	PIY	Average Incoming Quality (p_I) (Optimum for (p_T)	State variable from previous stage
3	PPY	Average Process Quality Level (p')	Decision variable
4	STAGE COST	Manufacturing Cost	Does not include raw material cost
5	FØ	Minimum Average Cost Thus Far (f_n)	$f_n = f_{n-1}$ + STAGE COST
6	LSUB	Suboptimal Indicator	(see Section 5.4)

Table 5.5 Assembly Station Quality Aggregation Output

COLUMN NUMBER	VARIABLE	DESCRIPTION	REMARKS
1	PAI	Aggregate Incoming Quality Level (p_{AI})	PAI = PIA1 + PIA2 - PIA1*PIA2
2	PIA1	(aggregate) incoming quality (optimum p_{AI} or PI1)	PIA1 = PI1 if the 1st tab = PAI of previous tab otherwise
3	PIA2	Average Incoming Quality (optimum PI2 for PAI)	State variable to the previous stage
4	FAI	Minimum Aggregate Cost	FAI = FI1 + FI2
5	ISUB	Alternative solution indicator	(see Section 5.4)

Table 5.6 shows the output generated by optimization with respect to p.

Table 5.6 Assembly Station Decision Variable Output

COLUMN NUMBER	VARIABLE	DESCRIPTION	REMARKS
1	PT	Average Outgoing Quality (p_T)	State variable
2	PIY	Average Incoming Quality (p_I) (optimum for PT)	PIY (PT) = opt. (PAI) PPY
3	PPY	Average Process Quality Level (p')	Decision variable
4	STAGE COST	Assembly Cost	Does not include raw material cost
5	FØ	Minimum average cost thus far (f_n)	$f_n = f_{n-1}$ + STAGE COST
6	LSUB	Suboptimal Indicator	(see Section 5.4)

5.3 Interpretation of Outputs and An Example

This section will discuss the interpretation of the outputs and the manual traceback procedure. The example of Figure 5.2 will be used as an illustration. Appendix A contains the computer output for this problem. It also contains the input card images.

When the solutions for a specified final AOQL at the last station (always an inspection station) is required, the summary report table would be sufficient for the source of actions for the system. The cost shown on the first line of the 13th column represents the minimum average cost incurred for the entire system for that particular value of the final AOQL.

Whenever the user needs to know the average total inspection or desires to examine plans for final AOQL values other than that specified, the complete outputs must be called. The latter can be obtained by intermediate outputs, station by station and the basic knowledge of dynamic programming trace-back.

5.3.1 Manual Trace-Back Procedure

In effect, the summary report table can be obtained manually through the intermediate outputs, station by station. Fortunately, for a specified final AOQL, the program has a certain routine to perform a trace-back internally. In what follows, we will demonstrate how the user can obtain the solutions to other values of AOQL. We will describe the procedure using the example in Appendix A with AOQL = 0.050.

Before we proceed to the example, the procedure is recapitulated as follow :

1. It is advisable to have the structure of the system in front of the user to reduce ambiguities in connecting the stations and the components.

2. Start from the last stage and proceed toward the first stage.

3. Start from last table to the first for each station.

4. Finish all stations in that stage before proceeding.

5. Table 5.7 below summarizes the state variables used to connect stations.

Table 5.7 State Variables Names - By Stations

TYPE OF STATION	OUTGOING STATE VARIABLE	INCOMING STATE VARIABLE	REMARKS
Inspection	AOQ	PIY	
Manufacturing	PT	PIY	
"n-component"	PT	PIY	the n^{th} table
Assembly	PAI(PIY from n^{th} table) PAI(PIA1 from $(n-1)^{st}$ table) ⋮ PAI(PIA1 from 2nd table)	PIA1 and PIA2* PIA1 and PIA2* ⋮ PIA1* and PIA2*	the $(n-1)^{st}$ table the $(n-2)^{nd}$ table the 1st table

* These are the average incoming qualities p_I of the n^{th} component to the 1^{st} component entering to that particualr "n-component" assembly station, respectively.

Figure 5.2 illustrates the structure of the system used, for an example: The final AOQL = 0.050.

The number above the line are the average quality values (optimum outgoing and incoming qualities).

Starting from the last table of the intermediate outputs, component #4, stage #5 which is the inspection station. The specified (system) average outgoing quality limit is 0.050 which yields the AOQ value of 0.049, n = 71, c = 6, and the required incoming quality (PIY) of 0.055.

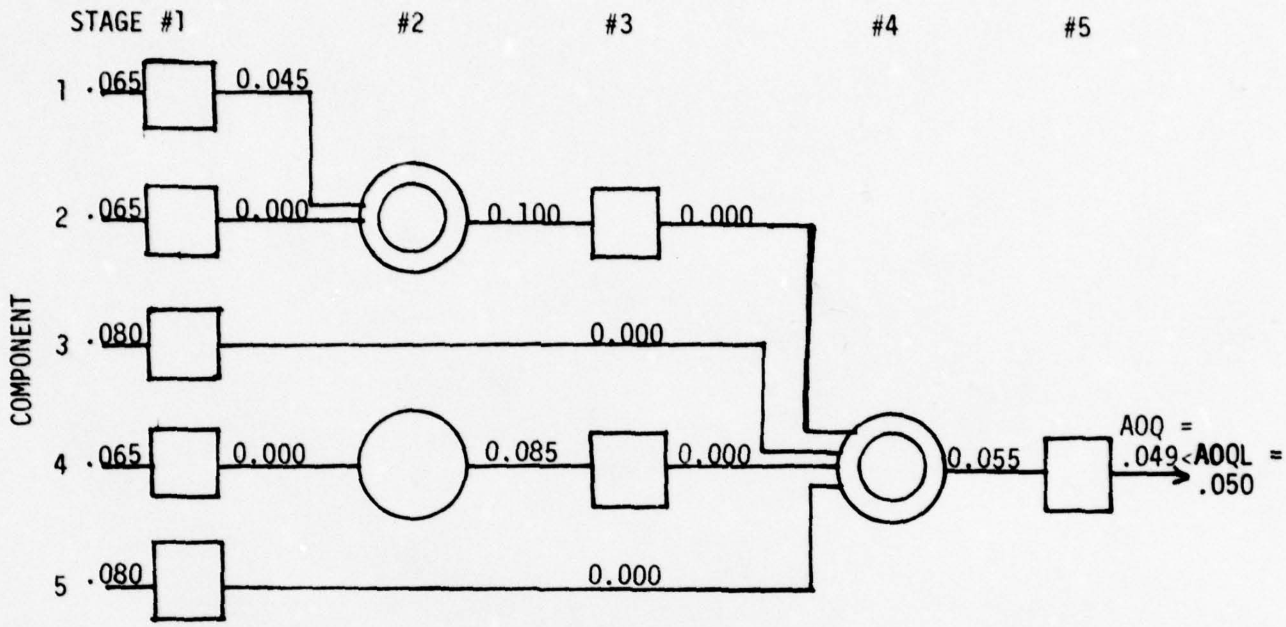

Figure 5.2 System Structure - An Example

In the table of the assembly station in Stage 4, the state variable used is PT (the average process outgoing quality) which is the PIY value obtained previously, i.e. 0.055. Consequently, the required average incoming quality (PIY) = 0.000 with PPY (the average process quality required) is 0.055.

In the table Component 5, Stage 4, the state variable for this table is PAI (the aggregate incoming quality) = 0.000. From PAI value, the PIA1 is 0.000 and the PIA2 is 0.000 which will be used as the state variable to the table of Component 5, Stage 1.

Entering table of Component 4, Stage 4 by the state variable PAI which is the value of PIA1 = 0.000 obtained previously, the PIA1 is now 0.000 and PIA2 is 0.000 which will be used as the state variable to the table of Component 4, Stage 3.

Again the latest PIA1 value, i.e. 0.000, is used for the state variable PAI of the table of Component 3, Stage 4. The new PIA1 is 0.000 and the PIA2 is 0.000. Since the present table is the first one for this assembly station (Component 4, Stage 4), the former value of 0.000 is the state variable AOQ value for the inspection station of Component 2, Stage 3. The later value of 0.000 is the state variable AOQ value for the inspection station of Component 3, Stage 1.

In the table of Component 4, Stage 3, an inspection station, the value of state variable (AOQ) is 0.000 obtained from the PIA2 value of the table of Component 4, Stage 4. The n and c values are 1000 and zero with PIY value (the required incoming quality level) equals 0.085.

In the table of Component 2, Stage 3, an inspection station, the value of AOQ is 0.000 obtained from the PIA1 value of the table of Component 4, Stage 4. The plan is n = 1000, c = 0, and the incoming quality level is 0.100 (PIY).

In the table of Component 4, Stage 2, a manufacturing station, the value of state variable P_T is 0.085 obtained from PIY value of table of Component 4, Stage 3. The required incoming quality level (PIY) = 0.000 and the average process average is 0.085.

In the assembly station in Stage 2, entering the table with the PIY value obtained from the table of Component 2, Stage 3 to the state variable P_T which is 0.100. The required incoming quality level (PIY) is 0.045 and the process quality level is 0.060.

Using the value of PIY obtained just above (0.045) as the state variable PAI of the table of Component 2, Stage 2, PIA1 and PIA2 values are 0.045 and 0.000. These values will be used as the state variable values (AOQ) for the tables of Component 1, Stage 1 and of Component 2 Stage 1,

respectively.

At Stage 1, all stations are inspection stations, we have already obtained the values of state variable AOQ for tables in Component 5 up to 1, which are 0.000, 0.000. 0.000. 0.000, and 0.045, respectively. The values of average incoming quality for raw materials are 0.065, 0.065, 0.080, 0.065 and 0.080, respectively.

Figure 5.3 gives the solution values to the system structure.

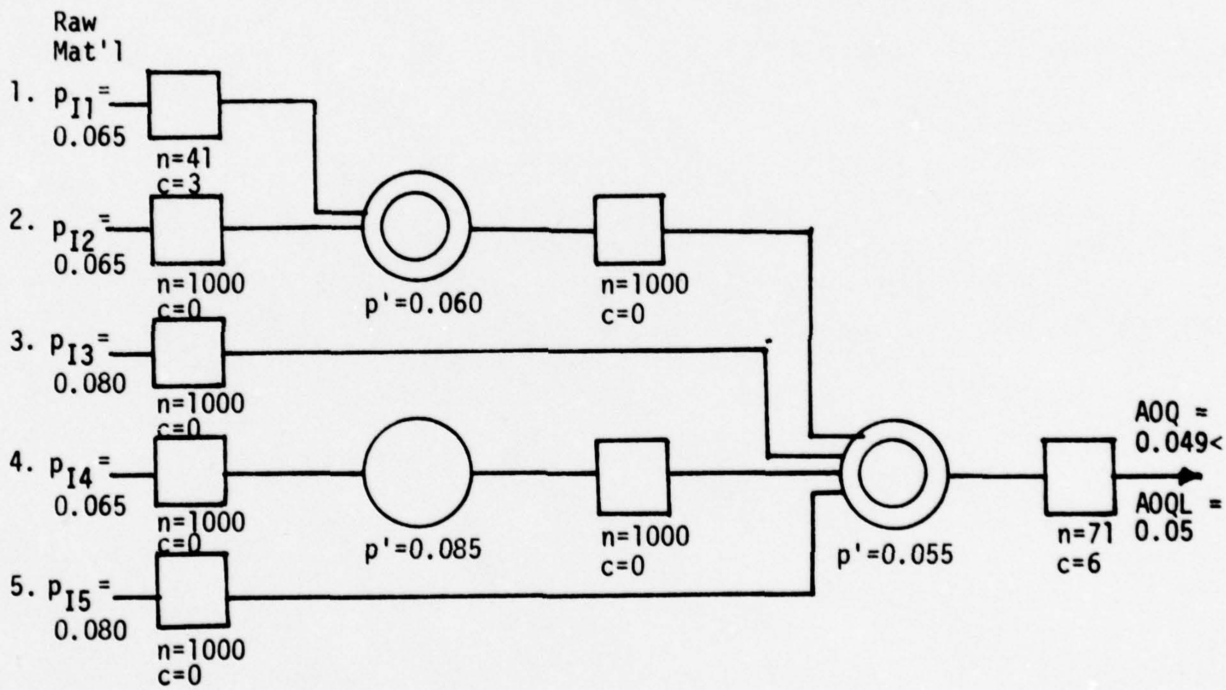

Figure 5.3 Solution to the Example

5.4 Suboptimal Conditions and Alternative Solutions

At any station there exists a suboptimal indicator variable for each value of the resulting quality. The indicator is 0, if, at that average outgoing quality, the value of decision variable is a global optimum; 1 if it is a "possible" local optimum. The variable is KSUB for inspection and LSUB for manufacturing or assembly. For an inspection station the sub-

optimal condition is caused when the average incoming quality, P_I, called for by the algorithm (see Chapter 2) is greater than the maximum average incoming quality, $P_{I\ max}$, for that particular station[1]. This means that the global optimum P_I^* might exist beyond the $P_{I\ max}$ value, had the maximum average incoming quality been greater than the current $P_{I\ max}$.

Another type of suboptimal indicator (ISUB), again zero or one, is involved in assembly stations where the ASSMBY subroutine is called for. In effect, the subroutine computes the aggregate incoming quality from a pair of components coming into assembly stations. ISUB equals 1 if an aggregate incoming quality formed by two sets of average incoming quality is greater than the maximum values of average incoming quality in either set, i.e.

$$PAI > \min [\max\ PI1, \max\ PI2]$$

Furthermore, the subroutine gives the indications of alternative solutions in the summary report table. The number indicates how many alternative combinations of P_{I1} and P_{I2} values the particular PAI has that yield the same incoming costs.

---

1 (see Ch. 3) $P_{I\ max} = \begin{cases} P_{Iraw} & : \text{No previous station} \\ AOQL \times FMAX & : \text{otherwise} \end{cases}$

6.0 POSSIBLE MODIFICATIONS TO THE PROGRAM

The program package as supplied can be easily modified to accomodate bigger size problems and/or other cost functions. Larger problems are discussed in Section 6.1. Other functional forms for cost functions are discussed in Section 4.4.3. If the input data is on cards, see Section 6.2.

6.1 How to Accomodate a Larger Problem

By changing the dimensions of arrays and vectors in the MAIN program one can increase the size of the problem that the program can solve. Twelve parameters are used to control the amount of storage area required in the computer. They are indicated and defined in Table 6.1.

The listing of the MAIN program is in Appendix B. By altering the DIMENSIØN Statements in the MAIN program according to the appropriate parameters, the size of the problem that the program can handle is altered.

It is advised that for a large problem, the program should be run, first, by adjusting only the MAXCØM and MAXSTG parameters to fit the problem. The program will determine the proper sizes of the other parameters for adjustment in the next run. The reason behind this approach is because the task of estimating the sizes of the various parameters is a rather time-consuming process and the allocation of too big a storage may be too costly.

Table 6.1 Parameter Definitions

Parameter	Definition
MAXCØM	Maximum number of components
MAXSTG	Maximum number of stages
J1	Total # of cost coordinate pairs for all RAW MATERIAL CØSTS
J2	Maximum number of cost coordinate pairs for a station or a raw material component
J3	Total # of cost coordinate pairs for processing stations and assembly stations
J4	Total # of inspection stations
J5	Number of values of AØQL $\frac{\text{(FINAL AØQL) * (FMAX)}}{\text{State Variable Grid Size}} + 1$
J6	Number of unique P_I values used to generate tables of ATI N and C. Note: J6 < < J7
J7	J1 + J5
J8	(# of components in the problem) *J5
J9	(Maximum # of components going into an assembly station) *J5
J10	Maximum of (J2, J6)

Other parameters that may need to be adjusted for input/output devices are in Table 6.2.

Table 6.2 Input/Output Device Parameters

Parameter	Definition
NRD	Input I/O-unit capable of rewinding
NWR	Output I/O-unit
NDS	I/O unit for random access file
NPRT	1 full output desired 0 partial output desired

6.2 Rewinding of Input Data File

As shown in Figure 4.1 (Schematic Diagram of Input/Output files),

it is required that the input data for a problem be put on a sequential data file which can be rewound by the program. The purpose of this feature is for the program to copy the data file image on the output for user verification, (see the example in Appendix A). The program rewinds the file and reads it again to interpret the data. It is possible to eliminate the rewinding step if one will sacrifice the printing of the input data image.

If the input data is on cards, the job control language associated with this program will be simplified if the rewinding step is eliminated. In order to accomplish this, statements with sequence numbers IPT 00039 to IPT 00050 (inclusive) of Subroutine INPUT must be deleted.

Note 1 The program as distributed will solve a system with up to 14 components and 15 stages.

Note 2 It took less than one minute of cpu plus I/O time to solve the example problem in Appendix A.

BIBLIOGRAPHY

Hassan, M. Z. and Knowles T. W., "An Optimal Quality Control Design for a Single-Product Serial Manufacturing System", Journal of Quality Technology, Vol. 11, No. 1, January, 1979.

Manaspiti, A., Semi-Economic Quality Systems Design for Multi-Product Manufacturing Environments Subject to Inspection Error, Unpublished Ph.D. Thesis, Illinois Institute of Technology, 1979.

Subramaniam, R., Design of Economic Quality Assurance Systems of Inter-Related Single Sampling Plans Using Dynamic Programming, Unpublished Ph.D. Thesis, Illinois Institute of Technology, 1976.

APPENDIX A

AN EXAMPLE OF THE OUTPUTS

```
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************************************************************************************
*                                                                                  *
* D E S I G N   O F   M A N U F A C T U R I N G   Q U A L I T Y   S Y S T E M    *
*                                                                                  *
************************************************************************************

DESIGN OF INCOMING QUALITY LEVEL , PROCESS QUALITY LEVEL AND OPTIMAL INTERRELATED
SINGLE SAMPLING PLANS FOR THE TOTAL MANUFACTURING SYSTEM.    THIS WORK WAS PARTIALLY
SUPPORTED BY THE OFFICE OF NAVAL RESEARCH UNDER CONTRACT NUMBER  N00014-76-C-0841

****************************************************************************************
*                                                                                      *
*              D A T A   F I L E   I M A G E   F O R   T H I S   R U N                 *
*                                                                                      *
****************************************************************************************

                        1         2         3         4         5         6         7         8
CARD IMAGE     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD NUMBER
         1     QUALITY CHARACTERISTICS                                          TEST DATA FILE
         2          .050      .005      2.00      1000                          TEST DATA FILE
         3     STRUCTURE                                                        TEST DATA FILE
         4              1    1I        2AONE                                    TEST DATA FILE
         5              2    1I        2AONE      3I         4ATWO              TEST DATA FILE
         6              3    1I        4ATWO                                    TEST DATA FILE
         7              4    1I        2M         3I         4ATWO     5I       TEST DATA FILE
         8              5    1I        4ATWO                                    TEST DATA FILE
         9     INSPECTION COSTS                                                 TEST DATA FILE
        10              1    1            9.00      0.45                        TEST DATA FILE
        11              2    1            7.50      0.25                        TEST DATA FILE
        12              3    1            9.00      0.45                        TEST DATA FILE
        13              4    1            7.50      0.25                        TEST DATA FILE
        14              2    3           10.00      0.50                        TEST DATA FILE
        15              4    3           13.00      0.50                        TEST DATA FILE
        16              4    5           19.00      4.00                        TEST DATA FILE
        17              5    1            9.00      0.45                        TEST DATA FILE
        18     RAW MATERIAL COSTS                                               TEST DATA FILE
        19              1    1                                                  TEST DATA FILE
        20                .005 .005 .100 0.06  12.                              TEST DATA FILE
        21              2    1                                                  TEST DATA FILE
        22                .005 .005 .100 0.03   9.                              TEST DATA FILE
        23              3    1                                                  TEST DATA FILE
        24                .005 .005 .100 0.06  10.                              TEST DATA FILE
        25              4    1                                                  TEST DATA FILE
        26                .005 .005 .100 0.03  10.                              TEST DATA FILE
```

```
                  5     1                                                   TEST DATA FILE
                    .005  .005  .100 0.06   10.                             TEST DATA FILE
        ASSEMBLY COSTS                                                      TEST DATA FILE
                  2     2     1                                             TEST DATA FILE
                    .005  .005  .100 0.07   3.0                             TEST DATA FILE
                  4     4     1                                             TEST DATA FILE
                    .005  .005  .100 0.10   5.0                             TEST DATA FILE
        MANUFACTURING COSTS                                                 TEST DATA FILE
                  4     2     1                                             TEST DATA FILE
                    .005  .005  .100 0.09   4.5                             TEST DATA FILE
        ENDATA                                                              TEST DATA FILE
```

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```
**************************************************
*                                                *
*  D E S C R I P T I O N S   O F   P R O B L E M *
*                                                *
**************************************************
```

FINAL AOQL	.050
STATE-VARIABLE GRID SIZE	.005
FMAX	2.000
LOT SIZE	1000

```
**************************************************
*     S T R U C T U R E   O F   P R O B L E M    *
**************************************************
```

STAGE / COMPONENT	1	2	3	4	5
1	I	AONE			
2	I	AONE	I	ATWO	
3	I			ATWO	
4	I	M	I	ATWO	I
5	I			ATWO	

```
*****************************************************
* NUMBER OF UNIQUE STATIONS IN ASSEMBLY CHART *
*****************************************************
```

STATION TYPE	A	I	M	TOTAL
	2	8	1	11

*** NUMBER OF COMPONENTS = 5
*** NUMBER OF STAGES = 5

*** % DENSITY OF CHART = 44.00

```
*************************
* SPECIFIED PARAMETERS *
*************************
```

	MAXCOM	MAXSTG	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
LIMIT OF PROGRAM	15	14	180	35	200	25	25	50	205	150	105	50
ACTUAL PROBLEM	5	5	100	20	60	8	21	21	121	105	84	21

* AVERAGE TOTAL INSPECTION TABLE ... ATI(AOQ, PI) *

AOQ \ PI	.000	.005	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070	.075	.080	.085	.090	.095	.100
.000	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
.005	******	******	501.0	667.6	750.5	800.9	834.3	857.3	875.3	889.4	900.8	910.1	917.4	923.8	928.7	933.8	937.9	941.5	944.7	948.0	950.6
.010	******	******	******	333.7	500.2	600.2	667.3	714.8	750.0	778.1	800.3	818.5	833.7	846.9	857.5	867.1	875.7	883.0	889.4	895.1	900.2
.015	******	******	******	******	250.2	400.1	501.0	571.5	625.7	667.0	700.1	727.6	750.9	770.2	786.0	800.9	813.1	824.5	834.2	842.3	850.7
.020	******	******	******	******	******	200.2	333.8	429.4	500.5	555.7	600.7	636.5	666.7	692.6	714.5	734.3	750.1	765.4	778.2	789.5	800.5
.025	******	******	******	******	******	******	167.6	286.3	375.9	445.0	500.9	545.8	583.5	615.8	643.1	666.7	688.2	705.9	722.5	737.8	750.1
.030	******	******	******	******	******	******	******	143.7	250.9	333.8	400.7	455.3	500.4	538.9	572.1	600.3	625.2	648.0	667.3	684.6	700.0
.035	******	******	******	******	******	******	******	******	125.8	222.8	300.0	364.4	416.9	462.4	500.9	534.1	562.7	588.4	612.1	632.2	650.2
.040	******	******	******	******	******	******	******	******	******	111.6	201.0	273.0	334.1	385.3	429.4	467.2	500.2	530.1	556.0	579.2	600.6
.045	******	******	******	******	******	******	******	******	******	******	100.8	182.6	250.5	307.8	357.7	400.9	438.3	470.7	500.4	526.8	550.9
.050	******	******	******	******	******	******	******	******	******	******	******	91.6	167.2	231.0	286.0	334.2	375.7	412.3	444.5	474.1	500.2
.055	******	******	******	******	******	******	******	******	******	******	******	******	83.5	154.5	215.2	267.6	313.2	353.7	389.2	421.2	450.5
.060	******	******	******	******	******	******	******	******	******	******	******	******	******	77.6	143.5	200.9	250.6	294.2	334.1	368.5	400.2
.065	******	******	******	******	******	******	******	******	******	******	******	******	******	******	72.4	134.3	186.2	235.3	278.3	316.3	350.7
.070	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	66.7	125.1	176.8	222.3	263.6	299.9
.075	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	62.8	117.9	167.2	211.0	250.4
.080	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	59.0	111.9	158.3	200.6
.085	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	55.7	105.5	150.5
.090	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	53.0	100.1
.095	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	50.2
.100	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******	******

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SAMPLE SIZE TABLE ... N(AOQ, PI)

AOQ \ PI	.000	.005	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070
.000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
.005	0	0	63	202	66	62	183	131	181	268	76	43	91	39	223
.010	0	0	0	195	33	115	174	131	65	381	129	100	152	244	85
.015	0	0	0	0	134	145	365	370	77	185	232	200	101	96	169
.020	0	0	0	0	0	54	182	181	174	40	18	251	222	150	83
.025	0	0	0	0	0	0	61	111	189	52	70	264	146	79	76
.030	0	0	0	0	0	0	0	81	58	224	128	171	105	130	125
.035	0	0	0	0	0	0	0	0	93	95	171	237	67	363	104
.040	0	0	0	0	0	0	0	0	0	98	145	59	87	99	46
.045	0	0	0	0	0	0	0	0	0	0	31	130	102	41	171
.050	0	0	0	0	0	0	0	0	0	0	0	56	3	125	198
.055	0	0	0	0	0	0	0	0	0	0	0	0	42	60	12
.060	0	0	0	0	0	0	0	0	0	0	0	0	0	14	36
.065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
.070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.075	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.085	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AOQ \ PI	.075	.080	.085	.090	.095	.100
.000	1000	1000	1000	1000	1000	1000
.005	147	91	33	83	94	47
.010	81	108	131	151	120	91
.015	132	112	246	90	74	95
.020	295	48	162	58	56	154
.025	244	185	68	247	109	188
.030	133	26	51	73	125	79
.035	88	73	94	46	181	75
.040	142	160	299	97	194	140
.045	200	163	84	203	332	116
.050	188	224	100	176	66	55
.055	146	259	124	83	209	15
.060	87	40	31	97	249	120
.065	112	170	19	160	73	220
.070	51	114	58	34	102	35
.075	0	36	58	15	103	88
.080	0	0	49	19	58	37
.085	0	0	0	20	91	134
.090	0	0	0	0	47	54
.095	0	0	0	0	0	37
.100	0	0	0	0	0	0

* ACCEPTANCE NUMBER TABLE ... C(AOQ, PI) *

AOQ \ PI	.000	.005	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070	.075	.080	.085	.090	.095	.100
.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.005	0	0	0	2	0	0	3	2	4	8	1	0	2	0	10	6	3	0	3	4	1
.010	0	0	0	4	0	2	4	3	1	15	4	3	6	12	3	3	5	7	9	7	5
.015	0	0	0	0	4	4	13	14	2	7	10	9	4	4	9	7	6	17	5	4	6
.020	0	0	0	0	0	2	7	7	7	1	0	13	12	8	4	20	2	11	3	3	12
.025	0	0	0	0	0	0	3	5	9	2	3	15	8	4	4	17	13	4	20	8	16
.030	0	0	0	0	0	0	0	5	3	13	7	10	6	8	8	9	1	3	5	10	6
.035	0	0	0	0	0	0	0	0	7	6	11	16	4	28	7	6	5	7	3	16	6
.040	0	0	0	0	0	0	0	0	0	9	11	4	6	7	3	11	13	27	8	18	13
.045	0	0	0	0	0	0	0	0	0	0	3	11	8	3	14	17	14	7	19	34	11
.050	0	0	0	0	0	0	0	0	0	0	0	6	0	11	18	17	21	9	17	6	5
.055	0	0	0	0	0	0	0	0	0	0	0	0	5	6	1	14	27	12	8	22	1
.060	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	9	4	3	10	28	13
.065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	14	21	2	18	8	26
.070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	16	7	4	12	4
.075	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	8	2	13	11
.080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	8	5
.085	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	15	21
.090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	9
.095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
.100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

****
* COMPONENT 1 STAGE 1 STATION TYPE I STATION NAME ' ' *
****

AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.080	1170.00	13920.00	0
.005	91	3	.080	1097.37	13847.37	0
.010	108	5	.080	1024.55	13774.55	0
.015	132	7	.075	901.03	13701.03	0
.020	295	20	.075	826.11	13626.11	0
.025	244	17	.075	750.08	13550.08	0
.030	125	8	.070	617.88	13475.02	0
.035	104	7	.070	540.94	13398.08	0
.040	46	3	.070	463.80	13320.94	0
.045	41	3	.065	318.57	13241.65	0
.050	125	11	.065	239.10	13162.18	0
.055	42	5	.060	82.71	13082.71	0
.060	0	0	.060	.00	13000.00	0
.065	0	0	.065	.00	12923.08	0
.070	0	0	.070	.00	12857.14	0
.075	0	0	.075	.00	12800.00	0
.080	0	0	.080	.00	12750.00	0
.085	0	0	.085	.00	12705.88	0
.090	0	0	.090	.00	12666.67	0
.095	0	0	.095	.00	12631.58	0
.100	0	0	.100	.00	12600.00	0

* COMPONENT 2 STAGE 1 STATION TYPE I STATION NAME ' ' *

AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.065	737.50	10199.04	0
.005	91	2	.060	642.17	10142.17	0
.010	152	6	.060	583.61	10083.61	0
.015	101	4	.060	525.62	10025.62	0
.020	222	12	.060	466.70	9966.70	0
.025	264	15	.055	361.59	9907.04	0
.030	171	10	.055	301.65	9847.11	0
.035	237	16	.055	241.45	9786.90	0
.040	145	11	.050	125.61	9725.60	0
.045	31	3	.050	63.02	9663.02	0
.050	0	0	.050	.00	9600.00	0
.055	0	0	.055	.00	9545.45	0
.060	0	0	.060	.00	9500.00	0
.065	0	0	.065	.00	9461.54	0
.070	0	0	.070	.00	9428.57	0
.075	0	0	.075	.00	9400.00	0
.080	0	0	.080	.00	9375.00	0
.085	0	0	.085	.00	9352.94	0
.090	0	0	.090	.00	9333.33	0
.095	0	0	.095	.00	9315.79	0
.100	0	0	.100	.00	9300.00	0

```
******************************************************************************
*                                                                            *
* COMPONENT   3    STAGE   1    STATION TYPE   I    STATION NAME  '       '  *
*                                                                            *
******************************************************************************
```

AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.080	1170.00	11920.00	0
.005	91	3	.080	1097.37	11847.37	0
.010	108	5	.080	1024.55	11774.55	0
.015	132	7	.075	901.03	11701.03	0
.020	295	20	.075	826.11	11626.11	0
.025	244	17	.075	750.08	11550.08	0
.030	125	8	.070	617.88	11475.02	0
.035	104	7	.070	540.94	11398.08	0
.040	46	3	.070	463.80	11320.94	0
.045	41	3	.065	318.57	11241.65	0
.050	125	11	.065	239.10	11162.18	0
.055	42	5	.060	82.71	11082.71	0
.060	0	0	.060	.00	11000.00	0
.065	0	0	.065	.00	10923.08	0
.070	0	0	.070	.00	10857.14	0
.075	0	0	.075	.00	10800.00	0
.080	0	0	.080	.00	10750.00	0
.085	0	0	.085	.00	10705.88	0
.090	0	0	.090	.00	10666.67	0
.095	0	0	.095	.00	10631.58	0
.100	0	0	.100	.00	10600.00	0

COMPONENT 4 STAGE 1 STATION TYPE I STATION NAME ' '

AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.065	737.50	11199.04	0
.005	91	2	.060	642.17	11142.17	0
.010	152	6	.060	583.61	11083.61	0
.015	101	4	.060	525.62	11025.62	0
.020	222	12	.060	466.70	10966.70	0
.025	264	15	.055	361.59	10907.04	0
.030	171	10	.055	301.65	10847.11	0
.035	237	16	.055	241.45	10786.90	0
.040	145	11	.050	125.61	10725.60	0
.045	31	3	.050	63.02	10663.02	0
.050	0	0	.050	.00	10600.00	0
.055	0	0	.055	.00	10545.45	0
.060	0	0	.060	.00	10500.00	0
.065	0	0	.065	.00	10461.54	0
.070	0	0	.070	.00	10428.57	0
.075	0	0	.075	.00	10400.00	0
.080	0	0	.080	.00	10375.00	0
.085	0	0	.085	.00	10352.94	0
.090	0	0	.090	.00	10333.33	0
.095	0	0	.095	.00	10315.79	0
.100	0	0	.100	.00	10300.00	0

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COMPONENT 5 STAGE 1 STATION TYPE I STATION NAME ' '

AOW	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.080	1170.00	11920.00	0
.005	91	3	.080	1097.37	11847.37	0
.010	108	5	.080	1024.55	11774.55	0
.015	132	7	.075	901.03	11701.03	0
.020	295	20	.075	826.11	11626.11	0
.025	244	17	.075	750.08	11550.08	0
.030	125	8	.070	617.88	11475.02	0
.035	104	7	.070	540.94	11398.08	0
.040	46	3	.070	463.80	11320.94	0
.045	41	3	.065	318.57	11241.65	0
.050	125	11	.065	239.10	11162.18	0
.055	42	5	.060	82.71	11082.71	0
.060	0	0	.060	.00	11000.00	0
.065	0	0	.065	.00	10923.08	0
.070	0	0	.070	.00	10857.14	0
.075	0	0	.075	.00	10800.00	0
.080	0	0	.080	.00	10750.00	0
.085	0	0	.085	.00	10705.88	0
.090	0	0	.090	.00	10666.67	0
.095	0	0	.095	.00	10631.58	0
.100	0	0	.100	.00	10600.00	0

COMPONENT 2 STAGE 2 STATION TYPE A STATION NAME 'ONE '

PAI	PIA1	PIA2	FAI	ISUB
.000	.000	.000	24119.04	0
.005	.005	.000	24046.41	0
.010	.010	.000	23973.59	0
.015	.015	.000	23900.06	0
.020	.020	.000	23825.14	0
.025	.025	.000	23749.12	0
.030	.030	.000	23674.06	0
.035	.035	.000	23597.12	0
.040	.040	.000	23519.98	0
.045	.045	.000	23440.69	0
.050	.050	.000	23361.21	0
.055	.055	.000	23281.75	0
.060	.060	.000	23199.04	0
.065	.065	.000	23122.11	0
.070	.070	.000	23056.18	0
.075	.075	.000	22999.04	0
.080	.070	.010	22940.76	0
.085	.070	.015	22882.76	0
.090	.070	.020	22823.84	0
.095	.050	.050	22762.18	0
.100	.065	.040	22648.68	1
.105	.070	.040	22582.75	1
.110	.070	.045	22520.17	1
.115	.070	.050	22457.14	1
.120	.075	.050	22400.00	1
.125	.075	.055	22345.45	1
.130	.080	.055	22295.45	1
.135	.080	.060	22250.00	1
.140	.085	.060	22205.88	1
.145	.090	.060	22166.67	1
.150	.090	.065	22128.20	1
.155	.095	.065	22093.12	1
.160	.095	.070	22060.15	1
.165	.100	.075	22000.00	1
.170	.100	.080	21975.00	1
.175	.100	.085	21952.94	1
.180	.100	.090	21933.33	1
.185	.100	.095	21915.79	1
.190	.100	.100	21900.00	1

ASSEMBLY STATION - AGGREGATE SOLUTION TABLE

STAGE 2 STATION NAME 'ONE '

PT	PIY	PPY	STAGE COST	FD	LSUB
.000	.000	.000			0
.005	.000	.005	17000.00	41119.04	0
.010	.000	.010	10000.00	34119.04	0
.015	.000	.015	7666.67	31785.70	0
.020	.000	.020	6500.00	30619.04	0
.025	.000	.025	5800.00	29919.04	0
.030	.000	.030	5333.33	29452.37	0
.035	.000	.035	5000.00	29119.04	0
.040	.000	.040	4750.00	28869.04	0
.045	.000	.045	4555.56	28674.59	0
.050	.000	.050	4400.00	28519.04	0
.055	.000	.055	4272.73	28391.77	0
.060	.000	.060	4166.67	28285.70	0
.065	.000	.065	4076.92	28195.96	0
.070	.000	.070	4000.00	28119.04	0
.075	.005	.070	4000.00	28046.41	0
.080	.010	.070	4000.00	27973.59	0
.085	.015	.070	4000.00	27900.06	0
.090	.020	.070	4000.00	27825.14	0
.095	.025	.070	4000.00	27749.12	0
.100	.045	.060	4166.67	27607.35	0

COMPONENT 4 STAGE 2 STATION TYPE M STATION NAME ' '

PT	PIY	PPY	STAGE COST	FO	LSUB
.000	.000	.000	**************	**********	0
.005	.000	.005	22500.00	33699.04	0
.010	.000	.010	13500.00	24699.04	0
.015	.000	.015	10500.00	21699.04	0
.020	.000	.020	9000.00	20199.04	0
.025	.000	.025	8100.00	19299.04	0
.030	.000	.030	7500.00	18699.04	0
.035	.000	.035	7071.43	18270.47	0
.040	.000	.040	6750.00	17949.04	0
.045	.000	.045	6500.00	17699.04	0
.050	.000	.050	6300.00	17499.04	0
.055	.000	.055	6136.36	17335.40	0
.060	.000	.060	6000.00	17199.04	0
.065	.000	.065	5884.62	17083.65	0
.070	.000	.070	5785.71	16984.75	0
.075	.000	.075	5700.00	16899.04	0
.080	.000	.080	5625.00	16824.04	0
.085	.000	.085	5558.82	16757.86	0
.090	.000	.090	5500.00	16699.04	0
.095	.005	.090	5500.00	16642.17	0
.100	.010	.090	5500.00	16583.61	0

****
* COMPONENT 2 STAGE 3 STATION TYPE 1 STATION NAME ' ' *
****

AOW	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.100	1500.00	29107.35	1
.005	47	1	.100	1425.89	29033.25	1
.010	91	5	.100	1350.35	28957.71	1
.015	95	6	.100	1276.08	28883.44	1
.020	154	12	.100	1200.77	28808.12	1
.025	188	16	.100	1125.19	28732.55	1
.030	79	6	.100	1049.99	28657.34	1
.035	75	6	.100	975.31	28582.67	1
.040	140	13	.100	900.86	28508.22	1
.045	116	11	.100	826.37	28433.72	1
.050	55	5	.100	750.26	28357.61	1
.055	15	1	.100	675.81	28283.17	1
.060	120	13	.100	600.37	28207.73	1
.065	220	26	.100	526.07	28133.42	1
.070	35	4	.100	449.92	28057.27	1
.075	88	11	.100	375.54	27982.90	1
.080	37	5	.100	300.94	27908.29	1
.085	134	21	.100	225.71	27833.06	1
.090	54	9	.100	150.18	27757.54	1
.095	37	8	.100	75.29	27682.65	0
.100	0	0	.100	.00	27607.35	0

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*                                                                       *
* COMPONENT    4    STAGE    3    STATION TYPE    1    STATION NAME  '  ' *
*                                                                       *
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AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	1000	0	.085	1605.00	18362.86	0
.005	91	3	.080	1444.41	18268.45	0
.010	108	5	.080	1348.56	18172.60	0
.015	112	6	.080	1252.21	18076.25	0
.020	48	2	.080	1155.16	17979.20	0
.025	244	17	.075	983.44	17882.48	0
.030	133	9	.075	885.38	17784.42	0
.035	88	6	.075	787.82	17686.86	0
.040	142	11	.075	689.13	17588.17	0
.045	171	14	.070	504.42	17489.18	0
.050	198	18	.070	403.29	17388.04	0
.055	12	1	.070	303.41	17288.16	0
.060	36	4	.070	202.33	17187.08	0
.065	0	0	.065	.00	17083.65	0
.070	0	0	.070	.00	16984.75	0
.075	0	0	.075	.00	16899.04	0
.080	0	0	.080	.00	16824.04	0
.085	0	0	.085	.00	16757.86	0
.090	0	0	.090	.00	16699.04	0
.095	0	0	.095	.00	16642.17	0
.100	0	0	.100	.00	16583.61	0

* COMPONENT 3 STAGE 4 STATION TYPE A STATION NAME 'TWO ' *

PAI	PIA1	PIA2	FAI	ISUB
.000	.000	.000	41027.35	0
.005	.005	.000	40953.24	0
.010	.010	.000	40877.71	0
.015	.015	.000	40803.44	0
.020	.020	.000	40728.12	0
.025	.025	.000	40652.55	0
.030	.030	.000	40577.34	0
.035	.035	.000	40502.67	0
.040	.040	.000	40428.22	0
.045	.000	.045	40349.00	0
.050	.000	.050	40269.53	0
.055	.000	.055	40190.07	0
.060	.000	.060	40107.35	0
.065	.000	.065	40030.43	0
.070	.005	.065	39956.32	0
.075	.010	.065	39880.79	0
.080	.015	.065	39806.51	0
.085	.020	.065	39731.20	0
.090	.025	.065	39655.62	0
.095	.050	.050	39519.79	0
.100	.040	.065	39431.29	1
.105	.045	.065	39356.80	1
.110	.050	.065	39280.69	1
.115	.055	.065	39206.24	1
.120	.060	.065	39130.80	1
.125	.065	.065	39056.50	1
.130	.070	.065	38980.35	1
.135	.075	.065	38905.98	1
.140	.080	.065	38831.37	1
.145	.085	.065	38756.14	1
.150	.090	.065	38680.61	1
.155	.095	.065	38605.73	1
.160	.100	.065	38530.43	1
.165	.100	.075	38407.35	1
.170	.100	.080	38357.35	1
.175	.100	.085	38313.24	1
.180	.100	.090	38274.02	1
.185	.100	.095	38238.93	1
.190	.100	.100	38207.35	1

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****
* COMPONENT 4 STAGE 4 STATION TYPE A STATION NAME 'TWO ' *
****

PAI	PIA1	PIA2	FAI	ISUB
.000	.000	.000	59390.22	0
.005	.000	.005	59295.80	0
.010	.000	.010	59199.95	0
.015	.000	.015	59103.60	0
.020	.000	.020	59006.55	0
.025	.000	.025	58909.83	0
.030	.000	.030	58811.78	0
.035	.000	.035	58714.21	0
.040	.000	.040	58615.52	0
.045	.000	.045	58516.53	0
.050	.000	.050	58415.40	0
.055	.000	.055	58315.52	0
.060	.000	.060	58214.44	0
.065	.000	.065	58111.01	0
.070	.000	.070	58012.11	0
.075	.000	.075	57926.39	0
.080	.000	.080	57851.39	0
.085	.010	.075	57776.75	0
.090	.010	.080	57701.75	0
.095	.020	.075	57627.16	0
.100	.040	.065	57511.87	1
.105	.035	.075	57401.70	1
.110	.035	.080	57326.70	1
.115	.045	.075	57248.04	1
.120	.050	.075	57168.57	1
.125	.055	.075	57089.11	1
.130	.060	.075	57006.39	1
.135	.065	.075	56929.47	1
.140	.065	.080	56854.47	1
.145	.075	.075	56779.82	1
.150	.075	.080	56704.82	1
.155	.095	.065	56603.44	1
.160	.095	.070	56504.54	1
.165	.100	.075	56330.33	1
.170	.100	.080	56255.33	1
.175	.110	.075	56179.73	1
.180	.110	.080	56104.73	1
.185	.120	.075	56029.84	1
.190	.120	.080	55954.84	1
.195	.130	.075	55879.39	1
.200	.130	.080	55804.39	1
.205	.135	.080	55730.01	1
.210	.125	.100	55640.11	1
.215	.140	.090	55530.41	1
.220	.150	.085	55438.48	1

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*************************************************************************
*                                                                       *
* COMPONENT    5    STAGE    4    STATION TYPE    A    STATION NAME  'TWO ' *
*                                                                       *
*************************************************************************
```

PAI	PIA1	PIA2	FAI	ISUB
.000	.000	.000	71310.21	0
.005	.005	.000	71215.80	0
.010	.010	.000	71119.95	0
.015	.015	.000	71023.60	0
.020	.020	.000	70926.55	0
.025	.025	.000	70829.83	0
.030	.030	.000	70731.77	0
.035	.035	.000	70634.21	0
.040	.040	.000	70535.52	0
.045	.045	.000	70436.53	0
.050	.050	.000	70335.39	0
.055	.055	.000	70235.52	0
.060	.060	.000	70134.43	0
.065	.065	.000	70031.01	0
.070	.070	.000	69932.11	0
.075	.075	.000	69846.39	0
.080	.080	.000	69771.39	0
.085	.085	.000	69696.75	0
.090	.090	.000	69621.75	0
.095	.095	.000	69547.16	0
.100	.100	.000	69431.87	1
.105	.105	.000	69321.70	1
.110	.110	.000	69246.70	1
.115	.115	.000	69168.04	1
.120	.100	.025	69061.95	1
.125	.105	.025	68951.78	1
.130	.105	.030	68876.72	1
.135	.115	.025	68798.12	1
.140	.120	.025	68718.65	1
.145	.130	.020	68632.50	1
.150	.135	.020	68555.57	1
.155	.135	.025	68479.55	1
.160	.105	.060	68401.70	1
.165	.165	.000	68250.33	1
.170	.170	.000	68175.33	1
.175	.120	.065	68091.64	1
.180	.170	.015	67956.36	1
.185	.165	.025	67880.41	1
.190	.165	.030	67805.35	1
.195	.165	.035	67728.41	1
.200	.165	.040	67651.27	1
.205	.165	.050	67492.51	1
.210	.165	.055	67413.04	1
.215	.165	.060	67330.33	1
.220	.165	.065	67253.41	1

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****************************************
*                                      *
* ASSEMBLY STATION - AGGREGATE SOLUTION TABLE *
*                                      *
* STAGE    4    STATION NAME   'TWO '   *
****************************************
```

PT	PIY	PPY	STAGE COST	FO	LSUB
.000	.000	.000	******************	********	0
.005	.000	.005	25000.00	96310.21	0
.010	.000	.010	15000.00	86310.21	0
.015	.000	.015	11666.67	82976.88	0
.020	.000	.020	10000.00	81310.21	0
.025	.000	.025	9000.00	80310.21	0
.030	.000	.030	8333.33	79643.55	0
.035	.000	.035	7857.14	79167.36	0
.040	.000	.040	7500.00	78810.21	0
.045	.000	.045	7222.22	78532.44	0
.050	.000	.050	7000.00	78310.21	0
.055	.000	.055	6818.18	78128.40	0
.060	.000	.060	6666.67	77976.88	0
.065	.000	.065	6538.46	77848.68	0
.070	.000	.070	6428.57	77738.79	0
.075	.000	.075	6333.33	77643.55	0
.080	.010	.070	6428.57	77548.52	0
.085	.015	.070	6428.57	77452.17	0
.090	.020	.070	6428.57	77355.12	0
.095	.025	.070	6428.57	77258.40	0
.100	.045	.060	6666.67	77103.20	0

COMPONENT 4 STAGE 5 STATION TYPE I STATION NAME ' '

AOQL	AOQ	N	C	PIY	STAGE COST	FO	KSUB
.000	.000	1000	0	.100	5900.00	83003.19	1
.005	.000	69	0	.100	5894.46	82997.66	1
.010	.004	36	0	.045	3928.79	82461.23	0
.015	.011	24	0	.045	3245.83	81778.27	0
.020	.018	137	5	.030	1542.22	81185.77	0
.025	.024	152	7	.035	1377.07	80544.42	0
.030	.028	130	7	.040	1261.01	80071.22	0
.035	.034	99	6	.040	928.20	79738.41	0
.040	.039	114	8	.050	1105.41	79415.63	0
.045	.044	66	5	.050	868.20	79178.41	0
.050	.049	71	6	.055	831.62	78960.02	0
.055	.055	65	6	.055	663.90	78792.30	0
.060	.059	79	8	.065	786.09	78634.76	0
.065	.064	74	8	.065	660.77	78509.44	0
.070	.068	52	6	.065	552.28	78400.96	0
.075	.075	57	7	.070	557.84	78296.62	0
.080	.076	53	7	.075	542.65	78186.19	0
.085	.082	50	7	.085	640.44	78092.61	0
.090	.085	61	9	.100	863.94	77967.13	1
.095	.087	45	7	.100	753.37	77856.57	1
.100	.089	49	8	.100	635.64	77738.83	1

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* OPTIMAL SOLUTION *

STATION NAME	STAGE	COMPO-NENT	TYPE OF STN	SAMPLING PLAN N	SAMPLING PLAN C	PROCESS FRAC. DEFECT	STATE VARIABLE AOQ	STATE VARIABLE AOQL	STATE VARIABLE PI	STATE VARIABLE PT	STAGE COST	MINIMUM EXPECTED COST F*	SUB OPT IND	ALT SOLN IND	REMARKS
	5	4	I	71	6		.049	.050	.055		831.6	78960.0	0		LAST STN
TWO	4	5	A			.055			.000	.055	6818.2	78128.4	0	0	*
	4	4	A						.000				0	0	*
	4	3	A						.000				0	0	*
	4	2	A						.000				0	0	*
	3	2	I	1000	0		.000	.000	.100		1500.0	29107.4	1		
	3	4	I	1000	0		.000	.000	.085		1605.0	18362.9	0		
ONE	2	2	A			.060			.000	.100	4166.7	27607.4	0	0	*
	2	1	A						.045				0	0	*
	2	4	M			.085			.000	.085	5558.8	16757.9	0		
	1	1	I	41	3		.045	.000	.065		318.6	13241.7	0		
	1	2	I	1000	0		.000	.000	.065		737.5	10199.0	0		
	1	3	I	1000	0		.000	.000	.080		1170.0	11920.0	0		
	1	4	I	1000	0		.000	.000	.065		737.5	11199.0	0		
	1	5	I	1000	0		.000	.000	.080		1170.0	11920.0	0		

E N D O F R E P O R T

@FIN . NIFQ

APPENDIX B

THE LISTING OF THE MAIN PROGRAM

```
WELT.L  WUE002*TUI.MAIN
ELT007C R72R1C 12/21/78 15:25:39 (4,)
000     C     ********************************************
000     C     * DESIGN OF MANUFACTURING QUALITY SYSTEM *
000     C     ********************************************
000     C
000     C     DESIGN OF INCOMING QUALITY LEVEL, PROCESS QUALITY LEVEL
004     C        AND OPTIMAL INTERRELATED LOT-BY-LOT SINGLE SAMPLING PLANS
004     C        FOR A SINGLE PRODUCT MULTI-COMPONENT MULTI-STAGE MANUFACTURING
004     C        SYSTEM.
000     C     THIS WORK WAS PARTIALLY SUPPORTED BY THE OFFICE OF NAVAL RESEARCH
000     C        UNDER CONTRACT NUMBER N00014-76-C-0841 .
000     C
000     C     PRINCIPAL INVESTIGATORS -
004     C        M. ZIA HASSAN AND THOMAS W. KNOWLES
000     C     REFERENCES -
000     C        BASED PARTIALLY ON PHD DISSERTATIONS BY R. SUBRAMANIUM AND
000     C        A. MANASPITI , DEPARTMENT OF MANAGEMENT SCIENCES, ILLINOIS
000     C        INSTITUTE OF TECHNOLOGY, CHICAGO, IL 60616 .
000     C
000     C     PROGRAMMERS -
000     C        APHAI MANASPITI AND PRICHA PANTUMSINCHAI
000     C
000     C     ***********************************************************************
004     C     ***********************************************************************
004     C     ***********************************************************************
000     C     ***********************************************************************
000     C
000     C     THE MAIN PROGRAM CONTROLS CALLING OF SUBROUTINES AND SETS THE
000     C     NECESSARY PARAMETERS TO ACCOMMODATE THE PROBLEM TO BE SOLVED.
000     C
000     C
000     C     ***********************************************************************
000     C
000     C     THESE ARRAYS AND VECTORS ARE CONTROLLED BY THE USER.
000     C
000     C     DIMENSION AOQ(J5),AOQL(J5),ATI(J5,J6),AOQY(J5),
000     C     C  C(J5,J6),CC(J3),CIN(J4,2),CRAW(J1),CT(J10),CY(J5),CYN(J5),
000     C     C  COR(J2,2),
000     C     F  FO(J5),FAI(J9),FON(J5),FI1(J9),FI2(J6),FM(J2),
000     C     I  ISUB(J9),IASM(MAXCOM),INDEX(MAXCOM,MAXSTG,2),INDX(J9),
000     C     I  IALT(J9),
000     C     K  KVEC(J6),KXI(MAXCOM),KCPRAW(MAXCOM,2),KSUB(J5),
000     C     L  LSUB(J5),
000     C     M  MODEL(MAXCOM,MAXSTG),MODL(MAXCOM,MAXSTG),
000     C     N  NPRVS(MAXCOM),NSTRUC(MAXCOM,MAXSTG),NSY(J5),NYN(J5),NSN(J5,J6),
000     C     N  NIPI(J7),NTPVS(MAXCOM),NFT(MAXCOM),NDX1(J9),NDX2(J9),
000     C     P  PO(J8),PFO(J8),PAI(J9),PIA1(J9),PIA2(J9),PIY(J5),PPY(J5),
000     C     P  PRAW(J1),PIYN(J5),PP(J3),PI(J6),PII(J9),PI2(J6),PM(J2),
000     C     Q  QT(J10),
000     C     T  TPC(J5),TISC(J5)
000     C
000     C     ***********************************************************************
000     C
000           INTEGER C,CY,CYN
000           COMMON /QC1/ IERROR,NRD,NWR,NDS
000           COMMON /QC3/ NPRT
```

```
000       COMMON /QC7/ J1,J2,J3,J4,MAXCOM,MAXSTG,I1,I2,I3,I4,J5,J6,J7,I5,I6,MIN00056
000      1I7,J8,J9,J10,I8,I9,I10                                           MIN00057
000    C                                                                   MIN00058
000    C ******************************************************************MIN00059
000    C                                                                   MIN00060
000    C  SET THE ARRAYS AND VECTORS CORRESPONDING TO THE PARAMETERS HERE  MIN00061
000    C                                                                   MIN00062
000       DIMENSION AOQ(25), AOQL(25), ATI(25,50), AOQY(25), C(25,50), CC(20MIN00063
000      10), CIN(25,2), CRAW(180), CT(50), CY(25), CYN(25), COR(35,2), FO(2MIN00064
000      25), FAI(105), FON(25), FI1(105), FI2(50), FM(35), ISUB(105), IASM(MIN00065
000      315), INDEX(15,14,2), INDX(105), IALT(105), KVEC(50), KXI(15), KCPRMIN00066
000      4AW(15,2), KSUB(25), LSUB(25), MODEL(15,14), MODL(15,14), NPRVS(15)MIN00067
000      5, NSTRUC(15,14), NSY(25), NYN(25), NSN(25,50), NIPI(205), NTPVS(15MIN00068
000      6), NFT(15), NDX1(105), NDX2(105), PO(150), PFO(150), PAI(105), PIAMIN00069
000      71(105), PIA2(105), PIY(25), PPY(25), PRAW(180), PIYN(25), PP(200),MIN00070
000      8 PI(50), PI1(105), PI2(50), PM(35), QT(50), TPC(25), TISC(25)    MIN00071
000    C                                                                   MIN00072
002    C  NOTE - IF NPRT = 1 INTERMEDIATE OUTPUT WILL BE PRODUCED          MIN00073
002    C         IF NPRT = 0 INTERMEDIATE OUTPUT WILL BE SUPPRESSED.       MIN00074
000       NPRT=1                                                           MIN00075
000    C                                                                   MIN00076
002    C  I/O UNITS - NRD=INPUT , NWR=OUTPUT , NDS=RANDOM ACCESS I/O       MIN00077
000       NRD=4                                                            MIN00078
000       NWR=6                                                            MIN00079
000       NDS=7                                                            MIN00080
000    C                                                                   MIN00081
000    C  PARAMETERS                                                       MIN00082
000       MAXCOM=15                                                        MIN00083
000       MAXSTG=14                                                        MIN00084
000       J1=180                                                           MIN00085
000       J2=35                                                            MIN00086
000       J3=200                                                           MIN00087
000       J4=25                                                            MIN00088
000       J5=25                                                            MIN00089
000       J6=50                                                            MIN00090
000       J7=205                                                           MIN00091
000       J8=150                                                           MIN00092
000       J9=105                                                           MIN00093
000       J10=50                                                           MIN00094
000    C                                                                   MIN00095
000    C ******************************************************************MIN00096
000    C                                                                   MIN00097
000       CALL INPUT (NSTRUC,IASM,MODEL,CRAW,PRAW,COR,CC,PP,CIN,KCPRAW,MODL,MIN00098
000      1INDEX,KXI,MAXNA)                                                 MIN00099
000       CALL ATINC (ATI,NSN,C,AOQL,PI,NIPI,PRAW,MAXNA)                   MIN00100
000       CALL DATOUT (CC,CIN,CRAW,INDEX,KCPRAW,MODEL,MODL,NSTRUC,PP,PRAW) MIN00101
000       CALL CONTRL (AOQ,AOQL,AOQY,ATI,C,CC,CIN,CRAW,CT,CY,CYN,FO,FAI,FON,MIN00102
000      1FI1,FI2,FM,ISUB,IASM,INDEX,KVEC,KXI,KCPRAW,KSUB,LSUB,NPRVS,NSTRUC,MIN00103
000      2NSY,NYN,NSN,NIPI,PO,PFO,PAI,PIA1,PIA2,PIY,PPY,PRAW,PIYN,PP,PI,PI1,MIN00104
000      3PI2,PM,QT,TPC,TISC,INDX,IALT,NTPVS,MODL,MODEL,NFT,NDX1,NDX2)     MIN00105
000       STOP                                                             MIN00106
000       END                                                              MIN00107

END ELT.

@FIN                                        NIFQ
```

APPENDIX C

THE LISTING OF THE SUBROUTINE COSTFN

```
WELT,L WDE002*TUI.COSTFN
ELT007C R72R1C 07/31/78 14:41:26 (4,)
004         SUBROUTINE COSTFN(NN,ICOM,JSTG,COR)
004   C
004   C           THIS SUBROUTINE GENERATES COORDINATES OF COST CURVES AS
004   C           SPECIFIED BY USERS. THERE ARE 9 FUNCTIONAL TYPES POSSIBLE.
004   C           THE STANDARD ONE PROVIDED HERE IS WHEN NCD=1 . OTHER
004   C           FORMS MAY BE SPECIFIED BY USERS WHEN NCD=2,3,...,9  .
004   C           LABELS ARE GIVEN.
004   C
004   C           THE FOLLOWING COMMON BLOCKS MUST REMAIN AT ALL TIME
004         COMMON/QC1/IERROR,NRD,NWR
004         COMMON/QC4/NVEC(20),NSTG(5),NAME(5),NAM(4)
004         COMMON/QC5/AOQLF,GRIDS,FMAX,LOTSZ,AF
004         COMMON/QC6/GRSZ,UN,UP,A(7),NUMCOR,NUMF,NUMT,NCD,NAP
004         COMMON/QC7/J1,J2,J3,J4,MAXCOM,MAXSTG,I1,I2,I3,I4
004   C
004         DIMENSION COR(J2,2)
004   C
004   C           WARNING & DO NOT CHANGE VALUES OF VARIABLES ALREADY DEFINED
004   C                     EXCEPT  FN  .
004   C                     DEFINITIONS OF VARIABLES  &-
004   C                             GRSZ = GRID SIZE OF QUALITY LEVEL P
004   C                               UN = LOWER LIMIT OF QUALITY LEVEL P
004   C                               UP = UPPER LIMIT OF QUALITY LEVEL P
004   C                     A(1),...,A(7) = CONSTANTS READ IN FOR A COST FUNCTION
004   C                                X = QUALITY LEVEL P
004   C                               FN = UNIT COST
004   C
004         IF(GRSZ.LE.0.OR.UN.LT.0.OR.UP.LE.UN.OR.UP.LE.0.) GO TO 40
004         IF(NCD.LT.0.OR.NCD.GT.9.OR.UN.GT.1..OR.UP.GT.1.) GO TO 40
004         BOUND=UP
004         IF(AF.LT.UP) BOUND=AF
004         I=0
004         X=UN-GRSZ
004      10 X=X+GRSZ
004         IF(X.GT.BOUND) GO TO 120
004      20 I=I+1
004   C
004         GO TO (1,2,3,4,5,6,7,8,9), NCD
004       1 FN=A(1)/X+A(2)
004         GO TO 30
004   C
004   C     *** THE FOLLOWING LABELLED STATEMENTS MAY BE ALTERED ***
004       2 FN=1/X
004         GO TO 30
004       3 FN=1/X
004         GO TO 30
004       4 FN=1/X
004         GO TO 30
004       5 FN=1/X
004         GO TO 30
004       6 FN=1/X
004         GO TO 30
004       7 FN=1/X
004         GO TO 30
004       8 FN=1/X
```

```
004          GO TO 30
004        9 FN=1/X
004     C
004     C    *** END ALTERABLE ***
004       30 COR(I,1)=X
004          COR(I,2)=FN
004          GO TO 10
004       40 GO TO (50,70,90), NN
004       50 WRITE(NWR,60) ICOM,NCD
004       60 FORMAT('0***** INPUT ERROR ***** RAW MATERIAL COSTS, COMPONENT',
004         1 I5,5X,'COST FUNCTION TYPE',I3)
004          GO TO 110
004       70 WRITE(NWR,80) ICOM,JSTG,NCD
004       80 FORMAT('0***** INPUT ERROR ***** PROCESSING COSTS   , COMPONENT',
004         1 I5,5X,'STAGE',I5,5X,'COST FUNCTION TYPE',I3)
004          GO TO 110
004       90 WRITE(NWR,100) ICOM,JSTG,NCD
004      100 FORMAT('0***** INPUT ERROR ***** ASSEMBLY COSTS , COMPONENT',I5,
004         1 5X,'STAGE',I5,5X,'COST FUNCTION TYPE',I3)
004      110 IERROR=1
004          RETURN
004      120 NUMCOR=1
004          IF(NUMCOR.GT.I2) I2=NUMCOR
004          IF(I2.LE.J2) RETURN
004          IERROR=1
004          WRITE(NWR,130)
004      130 FORMAT('0***** ERROR ***** J2 IS EXCEEDED')
004          RETURN
004          END

END ELT.
```